NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

SUPPLEMENTAL TO THESIS (1 of 1: Ephemeris and Error Data)

POWER SAVINGS THROUGH ONBOARD ORBIT PROPAGATION FOR SMALL SATELLITES LIKE NPSAT1

by

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LIST OF ACRONYMS AND ABBREVIATIONS

Anom	Anomaly
Arg	Argument
ECC	Eccentricity
INC	Inclination
JFCC SPACE	Joint Functional Component Commander Space
MM	Mean Motion
Obs	Observation
RAAN	Right Ascension of the Ascending Node
SGP-4	Simplified General Perturbations Propagator #4
TLE	Two-Line Element

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SUPPLEMENTAL SATELLITE DATA

A. CATALOG NUMBER 00162–TIROS 3

This ephemeris data represents one of three samples for inclinations 40–50 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 1. Two-Line Element for #00162 30NOV–7DEC15

Obs	TLE
1	1 162U 61017A 15334.77419749 -.00000044 +00000-0 +34121-4 0 9992
	2 162 047.8993 216.4029 0045393 286.7416 072.8499 14.43892330835072
2	1 162U 61017A 15335.88141797 -.00000061 +00000-0 +29335-4 0 9990
	2 162 047.8991 211.3790 0045371 291.3586 068.2468 14.43892528835237
3	1 162U 61017A 15337.88825627 -.00000074 +00000-0 +25609-4 0 9997
	2 162 047.8987 202.2730 0045321 299.7188 059.9199 14.43892842835529
4	1 162U 61017A 15338.85707525 -.00000072 +00000-0 +26163-4 0 9995
	2 162 047.8985 197.8769 0045295 303.7620 055.8962 14.43893035835668
5	1 162U 61017A 15339.89509588 -.00000067 +00000-0 +27710-4 0 9992
	2 162 047.8984 193.1668 0045273 308.0996 051.5818 14.43893251835814
6	1 162U 61017A 15341.00231826 -.00000054 +00000-0 +31513-4 0 9997
	2 162 047.8983 188.1427 0045244 312.7252 046.9835 14.43893488835971

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 2. Ephemeris Data Derived From TLEs for #00162

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	18 : 34 : 50.663	14.4389	0.0045393	47.8993	286.7416	216.4029	72.8499
2	1-Dec	21 : 9 : 14.513	14.4389	45371	47.8991	291.3586	211.3790	68.2468
3	3-Dec	21 : 19 : 5.342	14.4389	45321	47.8987	299.7188	202.2730	59.9199
4	4-Dec	20 : 34 : 11.302	14.4389	45295	47.8985	303.7620	197.8769	55.8962
5	5-Dec	21 : 28 : 56.284	14.4389	45273	47.8984	308.0996	193.1668	51.5818
6	7-Dec	0 : 3 : 20.298	14.4389	45244	47.8983	312.7252	188.1427	46.9835

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 3. Error of Propagated Ephemeris for #00162

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.195	489	26.57329
→3	0.541	1365	74.73741
→4	0.708	1775	97.98907
→5	0.882	2183	122.90156
→6	1.107	2641	149.47490
Obs 2→3	0.343	885	48.16412
→4	0.500	1304	71.41577
→5	0.662	1732	96.32827
→6	0.851	2200	122.90161
Obs 3→4	0.159	428	23.25166
→5	0.328	880	48.16415
→6	0.512	1362	74.73749
Obs 4→5	0.171	457	24.91250
→6	0.357	943	51.48583
Obs 5→6	0.190	489	26.57334

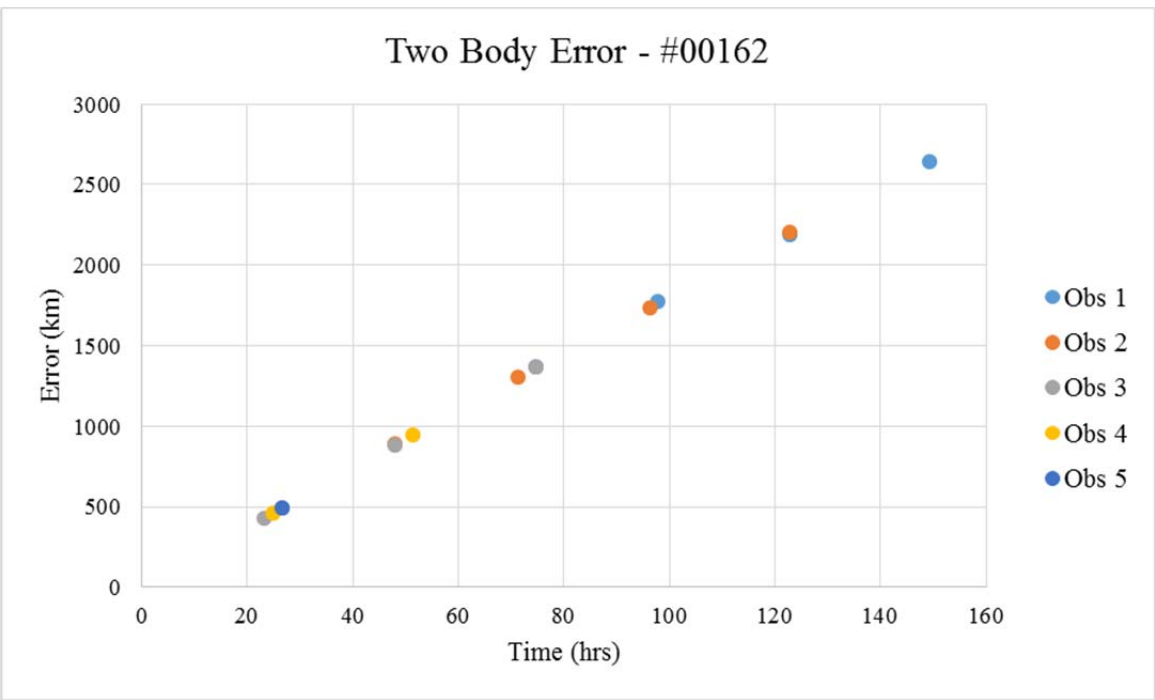

Figure 1. Error of the Two-Body Propagator Over Time–#00162

Figure 2. Error of the SGP-4 Propagator Over Time–#00162

B. CATALOG NUMBER 00226–RANGER 2

This ephemeris data represents one of three samples for inclinations 40–50 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 4. Two-Line Element for #00226 30NOV–6DEC15

Obs	TLE
1	1 226U 62002A 15334.87281593 -.00000029 +00000-0 +38766-4 0 9995
	2 226 048.2954 130.5867 0078650 249.9070 109.3352 14.45494461811196
2	1 226U 62002A 15336.87745949 -.00000030 +00000-0 +38494-4 0 9997
	2 226 048.2957 121.5365 0078691 258.0957 101.1110 14.45494962811482
3	1 226U 62002A 15337.84521941 -.00000033 +00000-0 +37677-4 0 9994
	2 226 048.2960 117.1675 0078697 262.0456 097.1506 14.45495222811625
4	1 226U 62002A 15339.84986706 -.00000033 +00000-0 +37819-4 0 9998
	2 226 048.2964 108.1177 0078703 270.2322 088.9559 14.45495819811917
5	1 226U 62002A 15340.81762894 -.00000015 +00000-0 +42678-4 0 9996
	2 226 048.2966 103.7488 0078710 274.1811 085.0095 14.45496198812059

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 5. Ephemeris Data Derived From TLEs for #00226

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	20 : 56 : 51.296	14.4549	0.007865	48.2954	249.9070	130.5867	109.3352
2	2-Dec	21 : 3 : 32.500	14.4549	78691	48.2957	258.0957	121.5365	101.1110
3	3-Dec	20 : 17 : 6.957	14.4550	78697	48.2960	262.0456	117.1675	97.1506
4	5-Dec	20 : 23 : 48.514	14.4550	78703	48.2964	270.2322	108.1177	88.9559
5	6-Dec	19 : 37 : 23.140	14.4550	78710	48.2966	274.1811	103.7488	85.0095

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 6. Error of Propagated Ephemeris for #00226

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.339	880	48.11145
→3	0.505	1302	71.33768
→4	0.876	2126	119.44923
→5	1.049	2524	142.67551
Obs 2→3	0.162	427	23.22624
→4	0.524	1293	71.33778
→5	0.695	1708	94.56407
Obs 3→4	0.358	878	48.11154
→6	0.530	1297	71.33783
Obs 4→5	0.168	426	23.22629

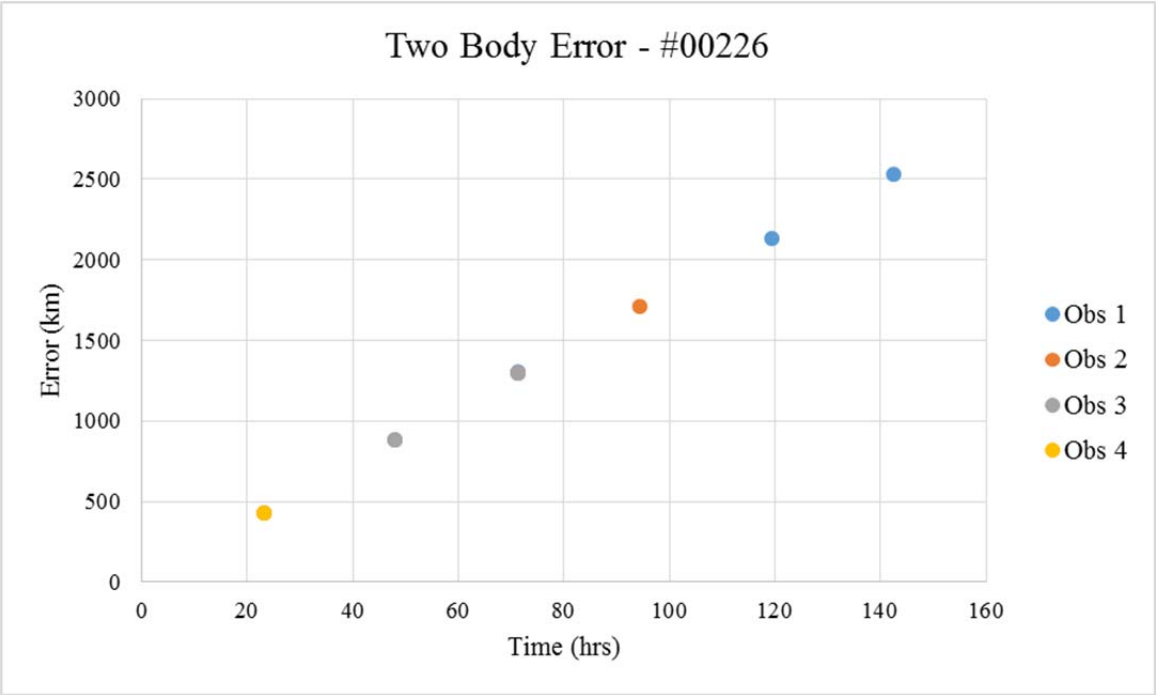

Figure 3. Error of the Two-Body Propagator Over Time–#00226

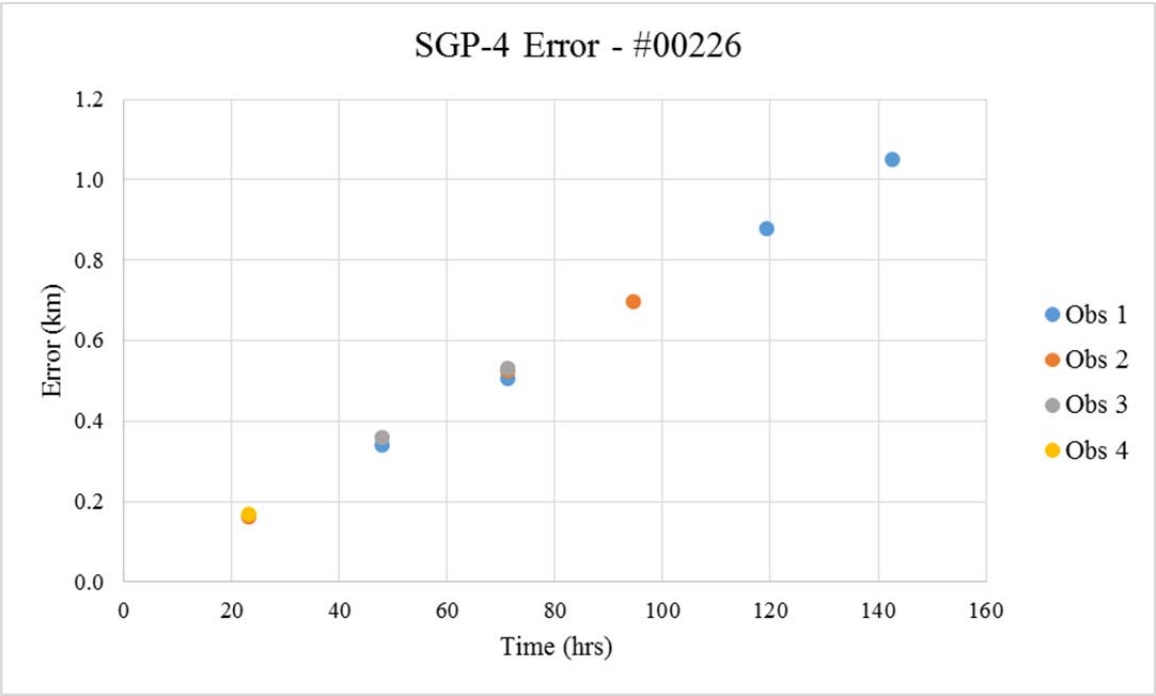

Figure 4. Error of the SGP-4 Propagator Over Time–#00226

C. CATALOG NUMBER 00355–THOR ABLESTAR DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.02-0.03 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 7. Two-Line Element for #00355 30NOV–7DEC15

Obs	TLE
1	1 355U 61015DV 15335.84621711 +.00000484 +00000-0 +96015-3 0 9993
	2 355 067.2208 096.3670 0251163 047.7785 031.8014 13.31450307636141
2	1 355U 61015DV 15336.76513449 +.00000421 +00000-0 +84896-3 0 9998
	2 355 067.2209 094.3731 0251148 047.1006 116.4060 13.31450925636261
3	1 00355U 61015DV 15337.79880940 .00000428 00000-0 86141-3 0 9997
	2 00355 67.2210 92.1301 0251135 46.3377 31.0774 13.31452101636879
4	1 355U 61015DV 15339.75102119 +.00000451 +00000-0 +90195-3 0 9990
	2 355 067.2212 087.8940 0251116 044.8926 028.5483 13.31454265636661
5	1 00355U 61015DV 15340.20168612 .00000445 00000-0 89050-3 0 9993
	2 00355 67.2212 86.9161 0251117 44.5597 28.7066 13.31454696637194
6	1 355U 61015DV 15340.74347578 +.00000479 +00000-0 +95021-3 0 9994
	2 355 067.2213 085.7406 0251123 044.1585 105.6519 13.31455396636795
7	1 355U 61015DV 15341.79811861 +.00000479 +00000-0 +95150-3 0 9994
	2 355 067.2213 083.4520 0251120 043.3784 120.8449 13.31456473636930

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 8. Ephemeris Data Derived From TLEs for #00355

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	20 : 18 : 33.158	13.3145	0.0251163	67.2208	47.7785	96.3670	31.8014
2	2-Dec	18 : 21 : 47.620	13.3145	251148	67.2209	47.1006	94.3731	116.4060
3	3-Dec	19 : 10 : 17.132	13.3145	251135	67.2210	46.3377	92.1301	31.0774
4	5-Dec	18 : 1 : 28.231	13.3145	251116	67.2212	44.8926	87.8940	28.5483
5	6-Dec	4 : 50 : 25.681	13.3145	251117	67.2212	44.5597	86.9161	28.7066
6	6-Dec	17 : 50 : 36.307	13.3146	251123	67.2213	44.1585	85.7406	105.6519
7	7-Dec	19 : 9 : 17.448	13.3146	251120	67.2213	43.3784	83.4520	120.8449

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 9. Error of Propagated Ephemeris for #00355

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.227	440	61.12160
→3	0.226	513	66.72954
→4	0.402	757	109.78062
→5	0.422	1482	115.57025
→6	1.143	1822	152.79138
→7	1.761	974	158.47719
Obs 2→3	0.360	43	5.60794
→4	1.100	335	48.65901
→5	1.280	699	54.44865
→6	0.626	1095	91.66978
→7	0.661	599	97.35559
Obs 3→4	0.561	296	43.05107
→5	0.698	626	48.84071
→6	0.366	1027	86.06184
→7	0.504	563	91.74765
Obs 4→5	0.085	74	5.78964
→6	0.155	514	43.01077
→7	0.399	299	48.69658
Obs 5→6	0.087	445	37.22113
→7	0.297	263	42.90694
Obs 6→7	0.259	34	5.68581

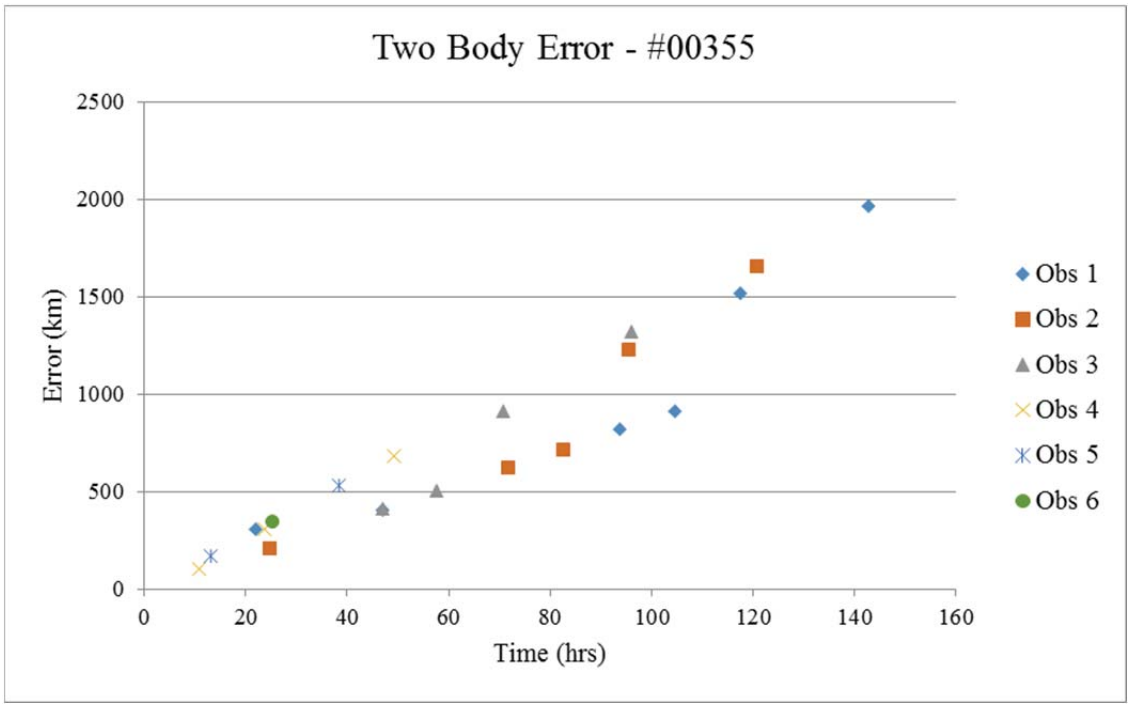

Figure 5. Error of the Two-Body Propagator Over Time–#00355

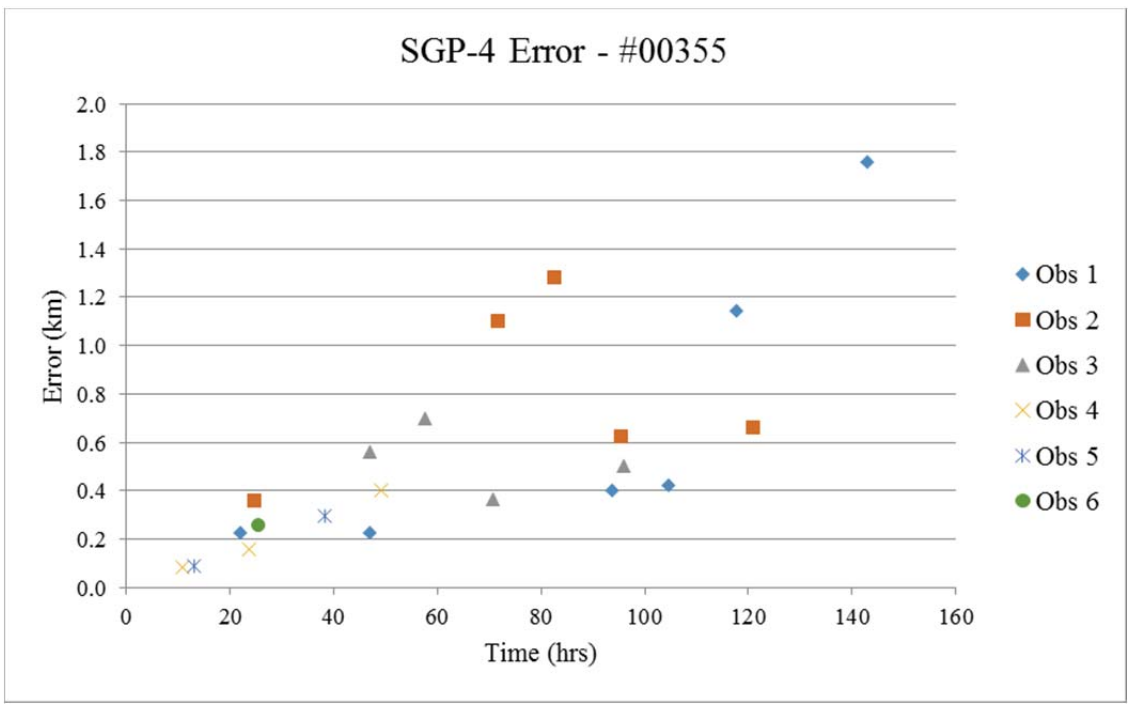

Figure 6. Error of the SGP-4 Propagator Over Time–#00355

D. CATALOG NUMBER 00643–THOR ABLESTAR DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.03-0.04 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 10. Two-Line Element for #00643 30NOV–7DEC15

Obs	TLE
1	1 643U 61015GU 15334.81770174 +.00000251 +00000-0 +50658-3 0 9992
	2 643 066.3709 078.1173 0340385 014.6176 346.4417 13.28688723597278
2	1 00643U 61015GU 15335.72094537 .00000264 00000-0 52698-3 0 9995
	2 00643 66.3709 76.0960 0340450 14.0904 346.9351 13.28689183597784
3	1 643U 61015GU 15336.69945815 +.00000320 +00000-0 +61682-3 0 9992
	2 643 066.3710 073.9061 0340529 013.5195 347.4693 13.28690177597529
4	1 00643U 61015GU 15337.67797043 .00000336 00000-0 64068-3 0 9997
	2 00643 66.3710 71.7162 0340612 12.9484 348.0036 13.28691004598040
5	1 00643U 61015GU 15339.10810217 .00000376 00000-0 70520-3 0 9990
	2 00643 66.3711 68.5157 0340739 12.1123 348.7857 13.28692542598238
6	1 643U 61015GU 15339.71026236 +.00000451 +00000-0 +82354-3 0 9999
	2 643 066.3711 067.1680 0340795 011.7623 349.1131 13.28693536597925
7	1 00643U 61015GU 15340.23715236 .00000454 00000-0 82892-3 0 9993
	2 00643 66.3711 65.9889 0340847 11.4545 349.4009 13.28694078598380
8	1 643U 61015GU 15340.68877201 +.00000535 +00000-0 +95778-3 0 9990
	2 643 066.3711 064.9782 0340883 011.1963 349.6423 13.28694992598053

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 11. Ephemeris Data Derived From TLEs for #00643

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	19 : 37 : 29.430	13.2869	0.0340385	66.3709	14.6176	78.1173	346.4417
2	1-Dec	17 : 18 : 9.680	13.2869	340450	66.3709	14.0904	76.0960	346.9351
3	2-Dec	16 : 47 : 13.184	13.2869	340529	66.3710	13.5195	73.9061	347.4693
4	3-Dec	16 : 16 : 16.645	13.2869	340612	66.3710	12.9484	71.7162	348.0036
5	5-Dec	2 : 35 : 40.027	13.2869	340739	66.3711	12.1123	68.5157	348.7857
6	5-Dec	17 : 2 : 46.668	13.2869	340795	66.3711	11.7623	67.1680	349.1131
7	6-Dec	5 : 41 : 29.964	13.2869	340847	66.3711	11.4545	65.9889	349.4009
8	6-Dec	16 : 31 : 49.902	13.2869	340883	66.3711	11.1963	64.9782	349.6423

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 12. Error of Propagated Ephemeris for #00643

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.100	288	21.67785
→3	0.440	600	45.16215
→4	0.875	912	68.64645
→5	1.971	1366	102.96961
→6	2.590	1556	117.42145
→7	3.157	1723	130.06681
→8	3.640	1865	140.90569
Obs 2→3	0.474	312	23.48431
→4	0.952	624	46.96860
→5	2.093	1078	81.29176
→6	2.721	1269	95.74361
→7	3.289	1436	108.38897
→8	3.899	1578	119.22784
Obs 3→4	0.298	312	23.48429
→5	1.074	767	57.80746
→6	1.514	958	72.25930
→7	1.896	1125	84.90466
→8	2.340	1268	95.74353
Obs 4→5	0.722	455	34.32316
→6	1.130	646	48.77501
→7	1.475	814	61.42037
→8	1.890	957	72.25924
Obs 5→6	0.293	191	14.45184
→7	0.520	359	27.09720
→8	0.832	502	37.93608
Obs 6→7	0.109	167	12.64536
→8	0.296	311	23.48423
Obs 7→8	0.194	143	10.83887

Figure 7. Error of the Two-Body Propagator Over Time–#00643

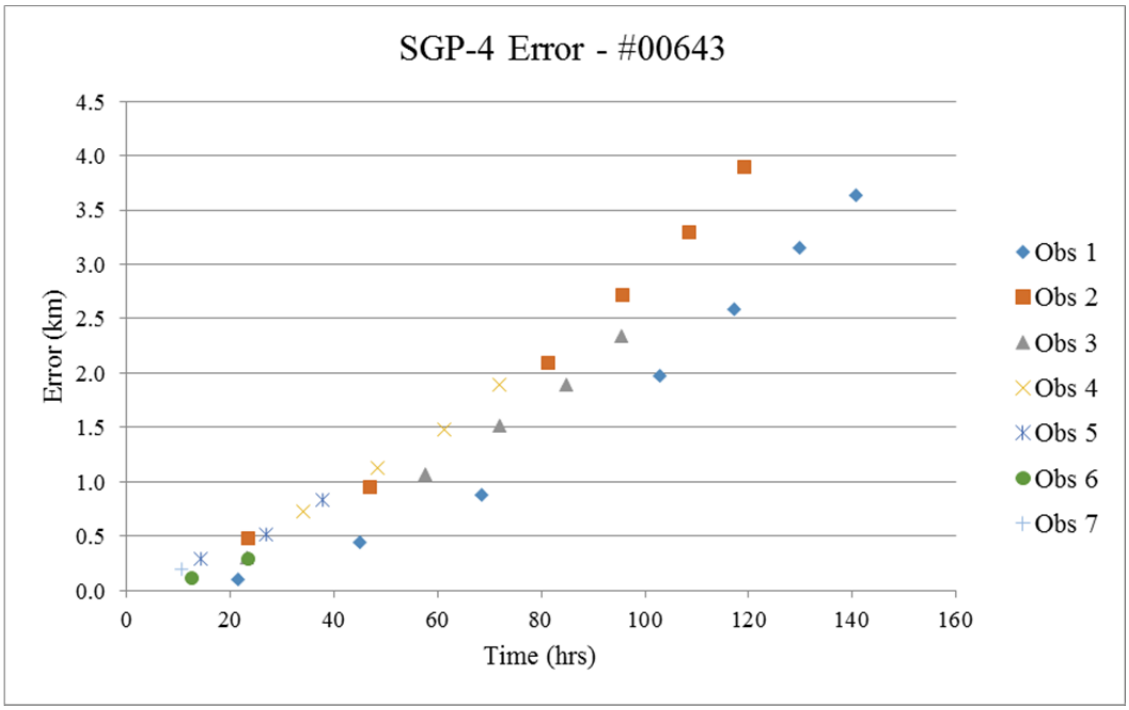

Figure 8. Error of the SGP-4 Propagator Over Time–#00643

E. CATALOG NUMBER 00705–TRANSIT 5E 3

This ephemeris data represents one of three samples for semi-major axes 7400–7500 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 13. Two-Line Element for #00705 30NOV–7DEC15

Obs	TLE
1	1 705U 63049C 15334.86647359 +.00000052 +00000-0 +69663-4 0 9999
	2 705 089.9294 105.1125 0034307 170.7749 355.0115 13.47272514553573
2	1 705U 63049C 15335.89322889 +.00000048 +00000-0 +62389-4 0 9994
	2 705 089.9295 105.1053 0034409 167.8680 294.9134 13.47272531553715
3	1 705U 63049C 15336.86951007 +.00000044 +00000-0 +56120-4 0 9994
	2 705 089.9296 105.0985 0034489 165.1205 349.9926 13.47272577553845
4	1 705U 63049C 15337.90803686 +.00000050 +00000-0 +66544-4 0 9997
	2 705 089.9297 105.0913 0034575 162.1991 346.9701 13.47272703553986
5	1 705U 63049C 15338.94116956 +.00000053 +00000-0 +71308-4 0 9996
	2 705 089.9298 105.0842 0034680 159.2833 317.7958 13.47272850554127
6	1 705U 63049C 15339.90708249 +.00000065 +00000-0 +89901-4 0 9996
	2 705 089.9299 105.0774 0034761 156.5754 322.5794 13.47273038554259
7	1 705U 63049C 15340.94680758 +.00000058 +00000-0 +78774-4 0 9994
	2 705 089.9301 105.0703 0034850 153.6621 325.3585 13.47273126554397

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 14. Ephemeris Data Derived From TLEs for #00705

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	20 : 47 : 43.318	13.4727	0.0034307	89.9294	170.7749	105.1125	355.0115
2	1-Dec	21 : 26 : 14.976	13.4727	34409	89.9295	167.8680	105.1053	294.9134
3	2-Dec	20 : 52 : 5.670	13.4727	34489	89.9296	165.1205	105.0985	349.9926
4	3-Dec	21 : 47 : 34.385	13.4727	34575	89.9297	162.1991	105.0913	346.9701
5	4-Dec	22 : 35 : 17.050	13.4727	34680	89.9298	159.2833	105.0842	317.7958
6	5-Dec	21 : 46 : 11.927	13.4727	34761	89.9299	156.5754	105.0774	322.5794
7	6-Dec	22 : 43 : 24.175	13.4727	34850	89.9301	153.6621	105.0703	325.3585

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 15. Error of Propagated Ephemeris for #00705

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.201	384	24.64213
→3	0.285	747	48.07288
→4	0.391	1134	72.99752
→5	0.592	1519	97.79270
→6	0.621	1877	120.97461
→7	0.713	2261	145.92802
Obs 2→3	0.122	364	23.43075
→4	0.186	752	48.35539
→5	0.295	1137	73.15058
→6	0.295	1496	96.33249
→7	0.348	1881	121.28589
Obs 3→4	0.061	387	24.92464
→5	0.115	773	49.71983
→6	0.129	1133	72.90174
→7	0.180	1519	97.85514
Obs 4→5	0.073	386	24.79518
→6	0.099	746	47.97710
→7	0.167	1133	72.93050
Obs 5→6	0.047	360	23.18191
→7	0.143	748	48.13531
Obs 6→7	0.151	388	24.95340

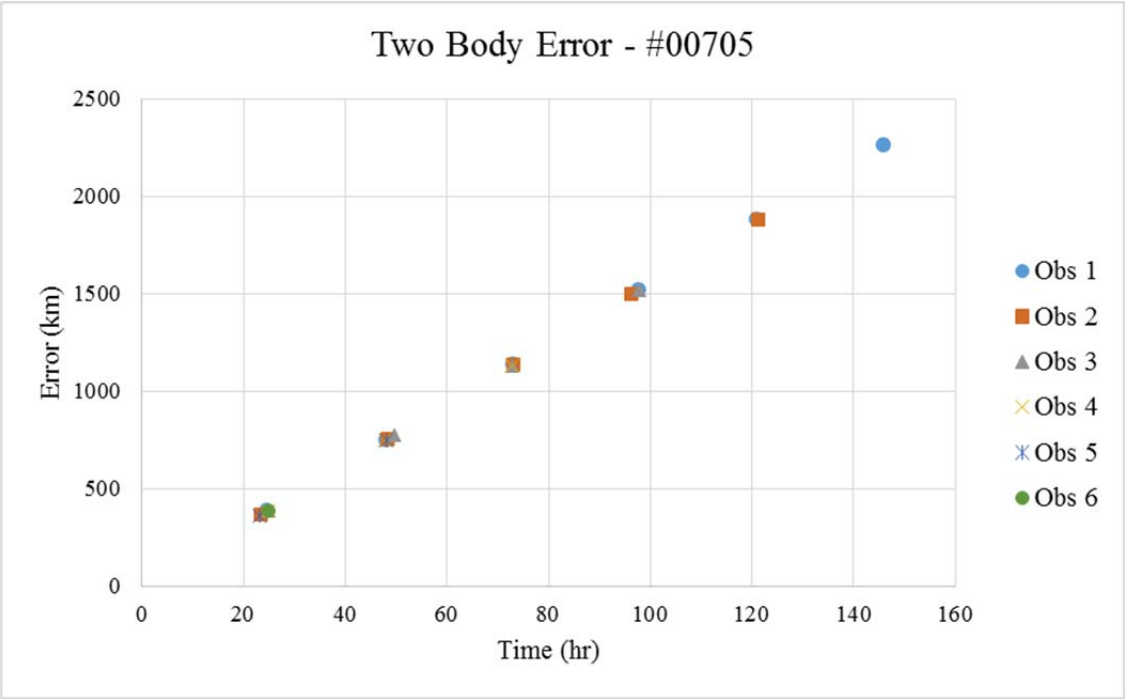

Figure 9. Error of the Two-Body Propagator Over Time–#00705

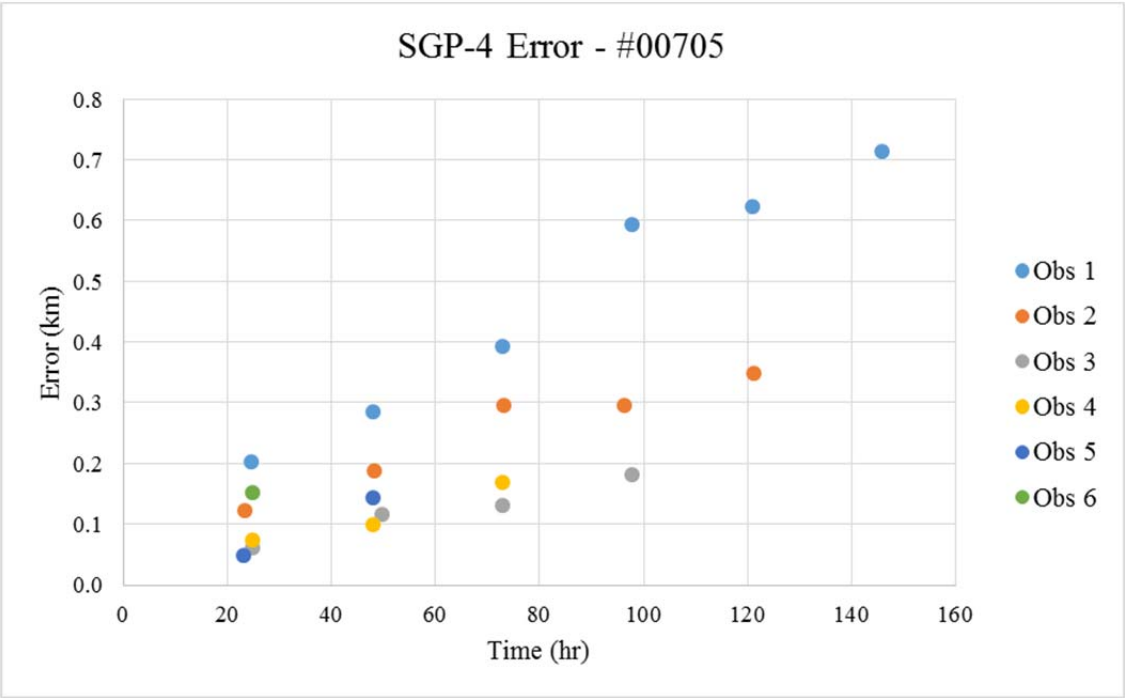

Figure 10. Error of the SGP-4 Propagator Over Time–#00705

F. CATALOG NUMBER 00716–TIROS 6

This ephemeris data represents one of three samples for inclinations 50–60 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 16. Two-Line Element for #00716 30NOV–7DEC15

Obs	TLE
1	1 716U 63054A 15334.63675308 +.00000142 +00000-0 +54936-4 0 9994
	2 716 058.4949 198.7780 0022431 358.8403 001.2579 14.69178901749323
2	1 716U 63054A 15335.92968065 +.00000093 +00000-0 +46691-4 0 9996
	2 716 058.4947 194.0182 0022620 000.4722 359.6333 14.69179420749516
3	1 716U 63054A 15336.88236370 +.00000064 +00000-0 +41837-4 0 9994
	2 716 058.4946 190.5110 0022762 001.6870 358.4241 14.69179841749658
4	1 716U 63054A 15337.90309521 +.00000045 +00000-0 +38591-4 0 9999
	2 716 058.4944 186.7531 0022912 002.9832 357.1338 14.69180296749805
5	1 716U 63054A 15338.92382642 +.00000038 +00000-0 +37447-4 0 9998
	2 716 058.4943 182.9953 0023069 004.2585 355.8645 14.69180787749951
6	1 716U 63054A 15339.87650853 +.00000086 +00000-0 +45510-4 0 9998
	2 716 058.4943 179.4880 0023215 005.4399 354.6887 14.69181519750096
7	1 716U 63054A 15340.96528769 +.00000109 +00000-0 +49360-4 0 9993
	2 716 058.4942 175.4796 0023390 006.7828 353.3522 14.69182201750251

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 17. Ephemeris Data Derived From TLEs for #00716

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	15 : 16 : 55.466	14.6918	0.0022431	58.4949	358.8403	198.7780	1.2579
2	1-Dec	22 : 18 : 44.408	14.6918	22620	58.4947	0.4722	194.0182	359.6333
3	2-Dec	21 : 10 : 36.224	14.6918	22762	58.4946	1.6870	190.5110	358.4241
4	3-Dec	21 : 40 : 27.426	14.6918	22912	58.4944	2.9832	186.7531	357.1338
5	4-Dec	22 : 10 : 18.603	14.6918	23069	58.4943	4.2585	182.9953	355.8645
6	5-Dec	21 : 2 : 10.337	14.6918	23215	58.4943	5.4399	179.4880	354.6887
7	6-Dec	23 : 10 : 0.856	14.6918	23390	58.4942	6.7828	175.4796	353.3522

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 18. Error of Propagated Ephemeris for #00716

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.191	507	31.03026
→3	0.346	880	53.89465
→4	0.594	1279	78.39221
→5	0.916	1676	102.88976
→6	1.26	2046	125.75413
→7	1.726	2466	151.88483
Obs 2→3	0.111	374	22.86439
→4	0.219	774	47.36195
→5	0.336	1173	71.85950
→6	0.453	1545	94.72387
→7	0.601	1968	120.85457
Obs 3→4	0.124	401	24.49756
→5	0.245	801	48.99511
→6	0.367	1174	71.85948
→7	0.515	1598	97.99018
Obs 4→5	0.133	401	24.49755
→6	0.279	774	47.36192
→7	0.467	1200	73.49262
Obs 5→6	0.143	374	22.86437
→7	0.331	801	48.99507
Obs 6→7	0.136	428	26.13070

Figure 11. Error of the Two-Body Propagator Over Time–#00716

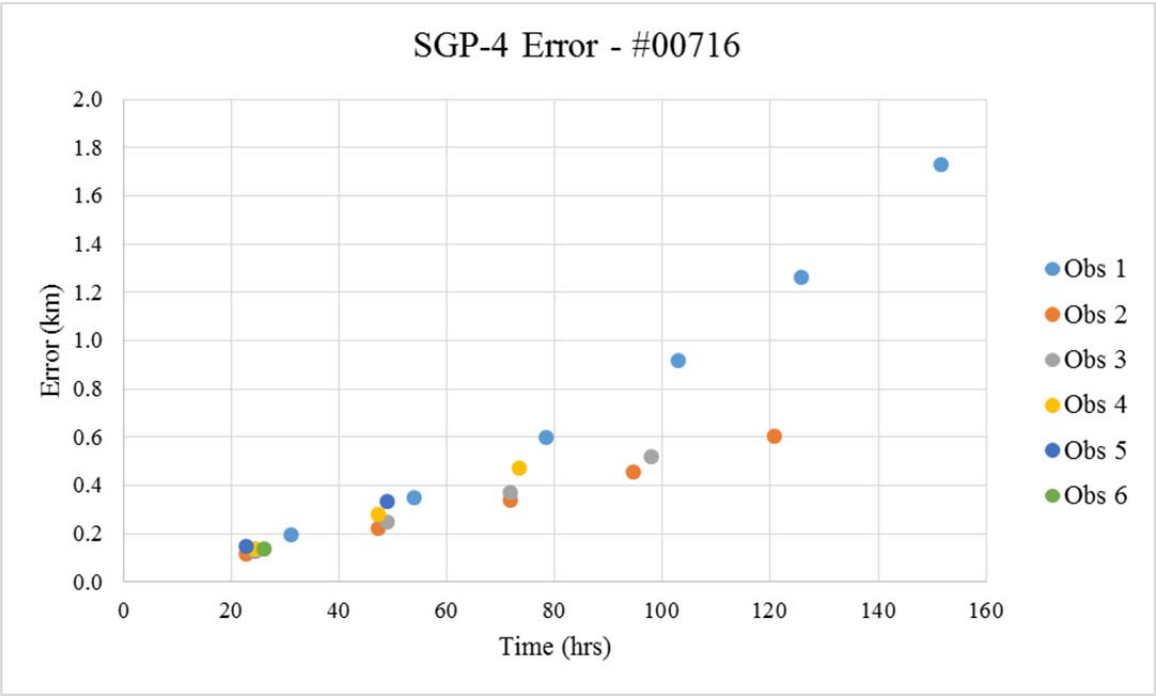

Figure 12. Error of the SGP-4 Propagator Over Time–#00716

G. CATALOG NUMBER 00801–TRANSIT 9

This ephemeris data represents one of three samples for semi-major axes 7400–7500 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 19. Two-Line Element for #00801 30NOV–7DEC15

Obs	TLE
1	1 00801U 64026A 15335.22358031 .00000294 00000-0 14800-3 0 9999
	2 00801 90.4989 333.0625 0048326 194.4282 165.5528 14.14204682641965
2	1 00801U 64026A 15336.49719363 .00000306 00000-0 15385-3 0 9991
	2 00801 90.4990 333.1337 0048481 190.2613 169.7590 14.14205355642146
3	1 00801U 64026A 15337.84156276 .00000288 00000-0 14481-3 0 9994
	2 00801 90.4990 333.2088 0048632 185.8908 174.1714 14.14205932642335
4	1 00801U 64026A 15339.18593104 .00000246 00000-0 12280-3 0 9997
	2 00801 90.4990 333.2840 0048814 181.5634 178.5408 14.14206512642526
5	1 00801U 64026A 15340.53029855 .00000254 00000-0 12683-3 0 9991
	2 00801 90.4990 333.3592 0049010 177.2675 182.8789 14.14207410642716
6	1 00801U 64026A 15341.87466560 .00000248 00000-0 12377-3 0 9990
	2 00801 90.4990 333.4343 0049160 172.9646 187.2242 14.14208118642907

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 20. Ephemeris Data Derived From TLEs for #00801

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	5 : 21 : 57.339	14.1420	0.0048326	90.4989	194.4282	333.0625	165.5528
2	2-Dec	11 : 55 : 57.530	14.1421	48481	90.4990	190.2613	333.1337	169.7590
3	3-Dec	20 : 11 : 51.022	14.1421	48632	90.4990	185.8908	333.2088	174.1714
4	5-Dec	4 : 27 : 44.442	14.1421	48814	90.4990	181.5634	333.2840	178.5408
5	6-Dec	12 : 43 : 37.795	14.1421	49010	90.4990	177.2675	333.3592	182.8789
6	7-Dec	20 : 59 : 31.108	14.1421	49160	90.4990	172.9646	333.4343	187.2242

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 21. Error of Propagated Ephemeris for #00801

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.162	517	30.56672
→3	0.399	1061	62.83158
→4	0.562	1604	95.09642
→5	0.699	2143	127.36124
→6	0.958	2680	159.62605
Obs 2→3	0.207	545	32.26486
→4	0.354	1089	64.52970
→5	0.495	1631	96.79452
→6	0.761	2170	129.05933
Obs 3→4	0.159	545	32.26484
→5	0.359	1088	64.52966
→6	0.432	1629	96.79447
Obs 4→5	0.335	544	32.26482
→6	0.552	1087	64.52963
Obs 5→6	0.123	543	32.26481

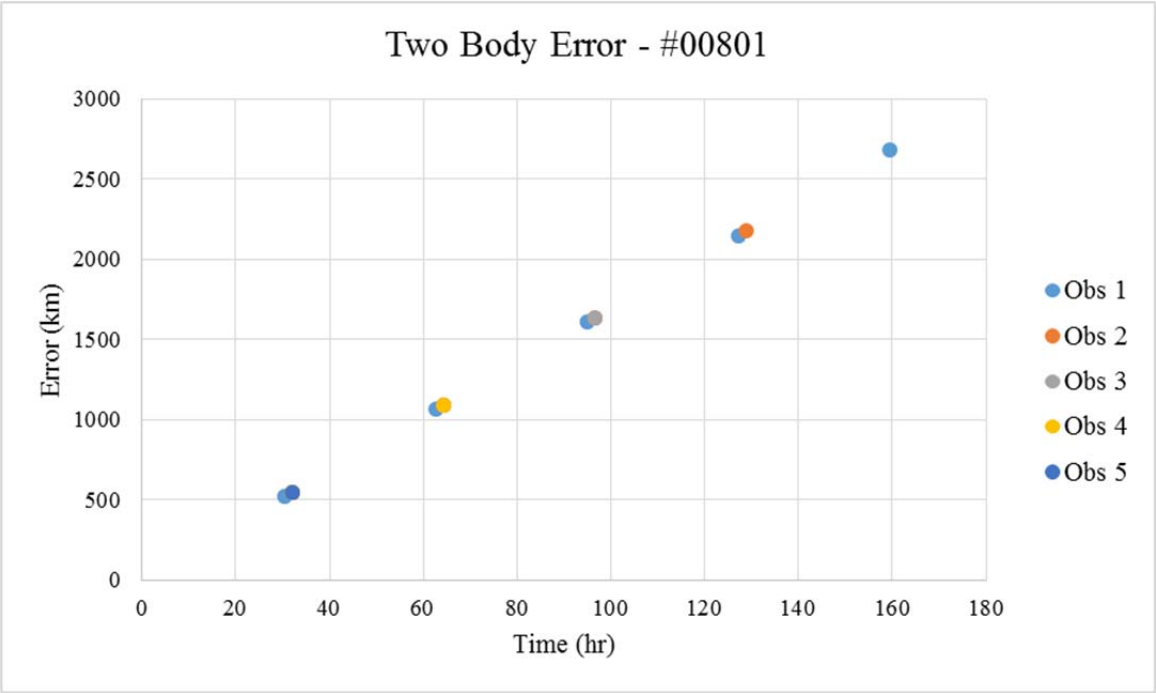

Figure 13. Error of the Two-Body Propagator Over Time–#00801

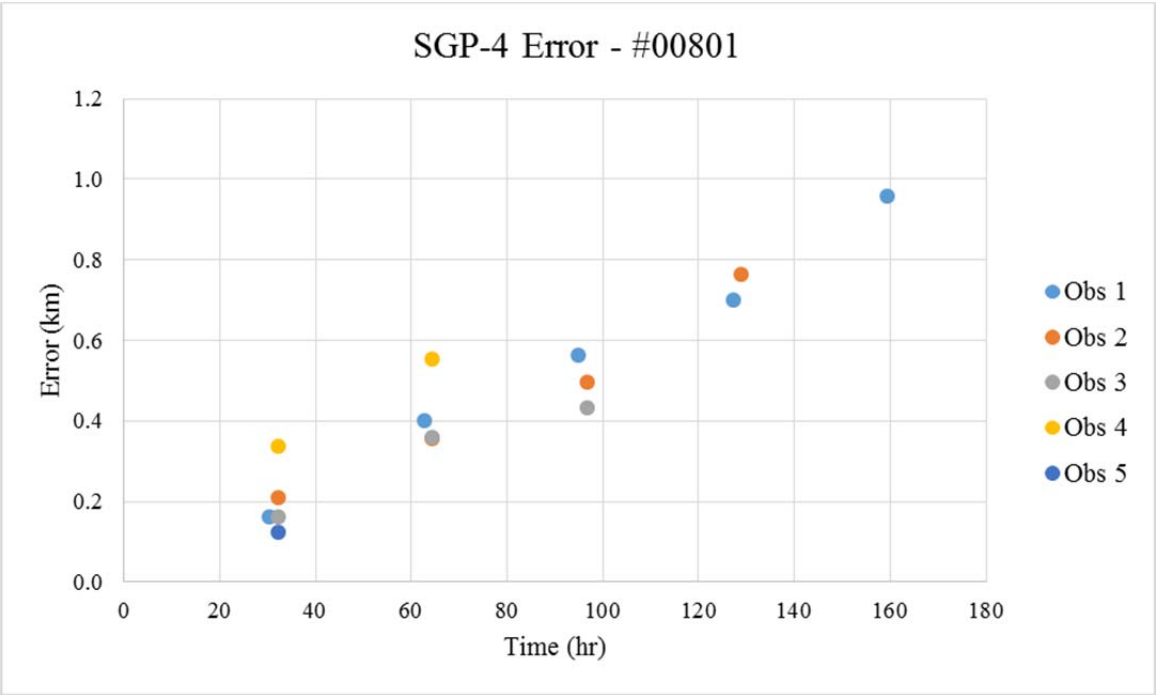

Figure 14. Error of the SGP-4 Propagator Over Time–#00801

H. CATALOG NUMBER 00900–CALSPHERE 1

This ephemeris data represents one of three samples for semi-major axes 7300–7400 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 22. Two-Line Element for #00900 30NOV–7DEC15

Obs	TLE
1	1 900U 64063C 15334.88516589 +.00000439 +00000-0 +46723-3 0 9995
	2 900 090.1399 003.0752 0026645 012.5879 347.5945 13.72586877542590
2	1 900U 64063C 15335.90575476 +.00000427 +00000-0 +45467-3 0 9990
	2 900 090.1398 003.0901 0026549 009.4993 350.6667 13.72587689542734
3	1 900U 64063C 15336.92634307 +.00000398 +00000-0 +42332-3 0 9997
	2 900 090.1397 003.1049 0026465 006.3979 353.7518 13.72588369542874
4	1 900U 64063C 15337.87403170 +.00000399 +00000-0 +42475-3 0 9993
	2 900 090.1397 003.1186 0026379 003.5132 356.6211 13.72589095543005
5	1 900U 64063C 15338.89461891 +.00000381 +00000-0 +40416-3 0 9994
	2 900 090.1396 003.1334 0026290 000.3981 359.7199 13.72589782543145
6	1 900U 64063C 15339.91520535 +.00000426 +00000-0 +45343-3 0 9993
	2 900 090.1395 003.1482 0026210 357.2641 002.8375 13.72590860543283
7	1 900U 64063C 15341.00869022 +.00000452 +00000-0 +48165-3 0 9997
	2 900 090.1394 003.1641 0026131 353.8963 006.1878 13.72591872543436

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 23. Ephemeris Data Derived From TLEs for #00900

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 14 : 38.333	13.7259	0.0026645	90.1399	12.5879	3.0752	347.5945
2	1-Dec	21 : 44 : 17.211	13.7259	26549	90.1398	9.4993	3.0901	350.6667
3	2-Dec	22 : 13 : 56.041	13.7259	26465	90.1397	6.3979	3.1049	353.7518
4	3-Dec	20 : 58 : 36.339	13.7259	26379	90.1397	3.5132	3.1186	356.6211
5	4-Dec	21 : 28 : 15.074	13.7259	26290	90.1396	0.3981	3.1334	359.7199
6	5-Dec	21 : 57 : 53.742	13.7259	26210	90.1395	357.2641	3.1482	2.8375
7	7-Dec	0 : 12 : 30.835	13.7259	26131	90.1394	353.8963	3.1641	6.1878

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 24. Error of Propagated Ephemeris for #00900

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.07	393	24.49413
→3	0.149	785	48.98825
→4	0.297	1148	71.73278
→5	0.493	1538	96.22687
→6	0.609	1926	120.72095
→7	0.832	2341	146.96458
Obs 2→3	0.065	392	24.49412
→4	0.174	756	47.23865
→5	0.312	1147	71.73274
→6	0.373	1536	96.22681
→7	0.508	1952	122.47045
Obs 3→4	0.066	364	22.74453
→5	0.135	755	47.23862
→6	0.237	1146	71.73269
→7	0.336	1562	97.97633
Obs 4→5	0.071	392	24.49409
→6	0.2	782	48.98817
→7	0.312	1200	75.23180
Obs 5→6	0.203	391	24.49407
→7	0.402	809	50.73771
Obs 6→7	0.062	419	26.24364

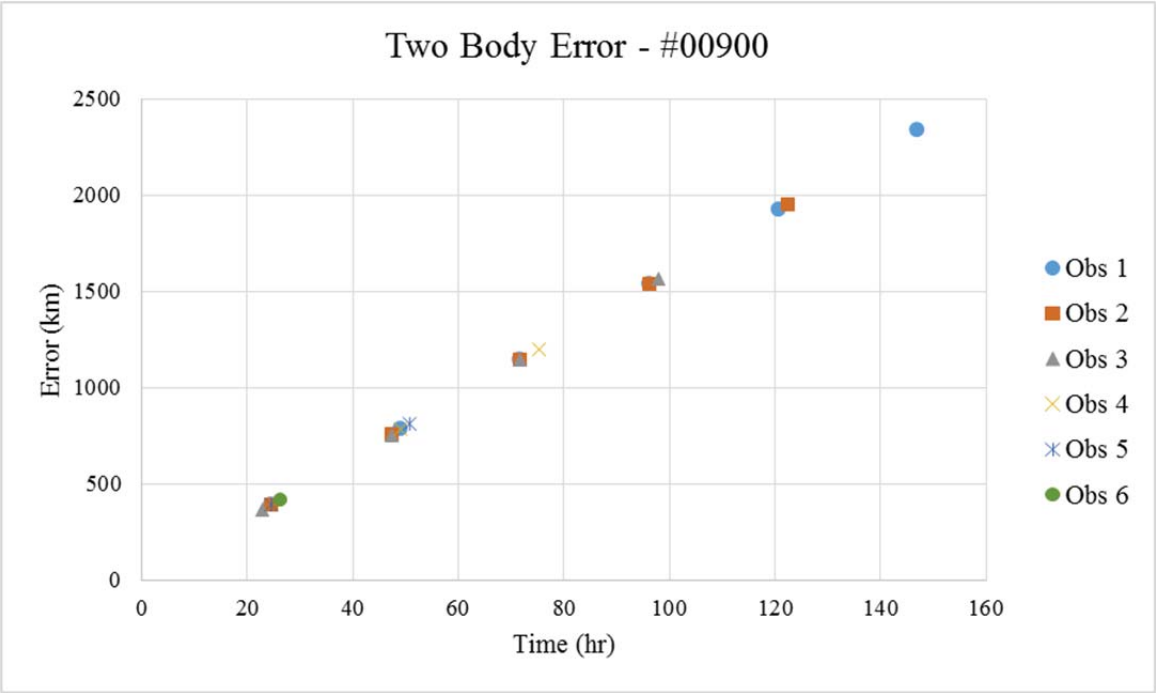

Figure 15. Error of the Two-Body Propagator Over Time–#00900

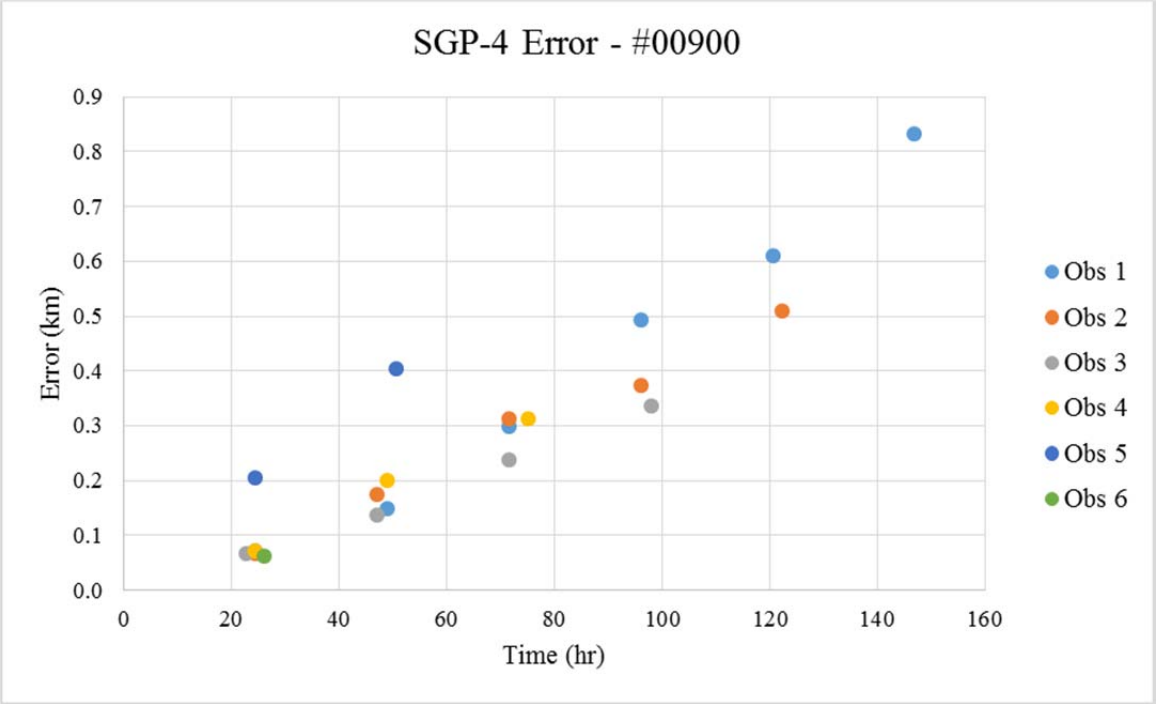

Figure 16. Error of the SGP-4 Propagator Over Time–#00900

I. CATALOG NUMBER 00902–CALSPHERE 2

This ephemeris data represents one of three samples for semi-major axes 7400–7500 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 25. Two-Line Element for #00902 30NOV–7DEC15

Obs	TLE
1	1 902U 64063E 15334.82331303 +.00000010 +00000-0 +15815-5 0 9995
	2 902 090.1438 005.4005 0016395 243.9915 163.9374 13.52623056335590
2	1 902U 64063E 15335.87426309 +.00000009 +00000-0 -40199-7 0 9996
	2 902 090.1437 005.4157 0016446 240.6075 241.8117 13.52623078335736
3	1 902U 64063E 15336.90924865 +.00000013 +00000-0 +65210-5 0 9994
	2 902 090.1437 005.4306 0016503 237.3103 241.9069 13.52623101335870
4	1 902U 64063E 15337.58481015 +.00000014 +00000-0 +74801-5 0 9991
	2 902 090.1436 005.4403 0016541 235.1642 291.6998 13.52623114335960
5	1 902U 64063E 15338.00875475 +.00000015 +00000-0 +89214-5 0 9991
	2 902 090.1436 005.4464 0016567 233.8114 196.1957 13.52623116336028
6	1 902U 64063E 15339.64716383 +.00000033 +00000-0 +36409-4 0 9991
	2 902 090.1434 005.4699 0016669 228.6496 254.7409 13.52623252336242
7	1 902U 64063E 15341.03421546 +.00000049 +00000-0 +59961-4 0 9996
	2 902 090.1432 005.4899 0016768 224.2637 169.2696 13.5262339533643

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 26. Ephemeris Data Derived From TLEs for #00902

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	19 : 45 : 34.246	13.5262	0.0016395	90.1438	243.9915	5.4005	163.9374
2	1-Dec	20 : 58 : 56.331	13.5262	16446	90.1437	240.6075	5.4157	241.8117
3	2-Dec	21 : 49 : 19.083	13.5262	16503	90.1437	237.3103	5.4306	241.9069
4	3-Dec	14 : 2 : 7.597	13.5262	16541	90.1436	235.1642	5.4403	291.6998
5	4-Dec	0 : 12 : 36.410	13.5262	16567	90.1436	233.8114	5.4464	196.1957
6	5-Dec	15 : 31 : 54.955	13.5262	16669	90.1434	228.6496	5.4699	254.7409
7	7-Dec	0 : 49 : 16.216	13.5262	16768	90.1432	224.2637	5.4899	169.2696

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 27. Error of Propagated Ephemeris for #00902

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.102	395	25.22280
→3	0.248	784	50.06245
→4	0.212	1036	66.27593
→5	0.41	1198	76.45060
→6	0.467	1809	115.77242
→7	0.445	2327	149.06166
Obs 2→3	0.158	389	24.83965
→4	0.145	642	41.05313
→5	0.317	803	51.22780
→6	0.402	1416	90.54962
→7	0.377	1936	123.83886
Obs 3→4	0.057	254	16.21348
→5	0.168	414	26.38815
→6	0.296	1028	65.70996
→7	0.306	1549	98.99920
Obs 4→5	0.076	160	10.17467
→6	0.216	775	49.49649
→7	0.245	1296	82.78573
Obs 5→6	0.147	616	39.32182
→7	0.197	1137	72.61106
Obs 6→7	0.133	522	33.28924

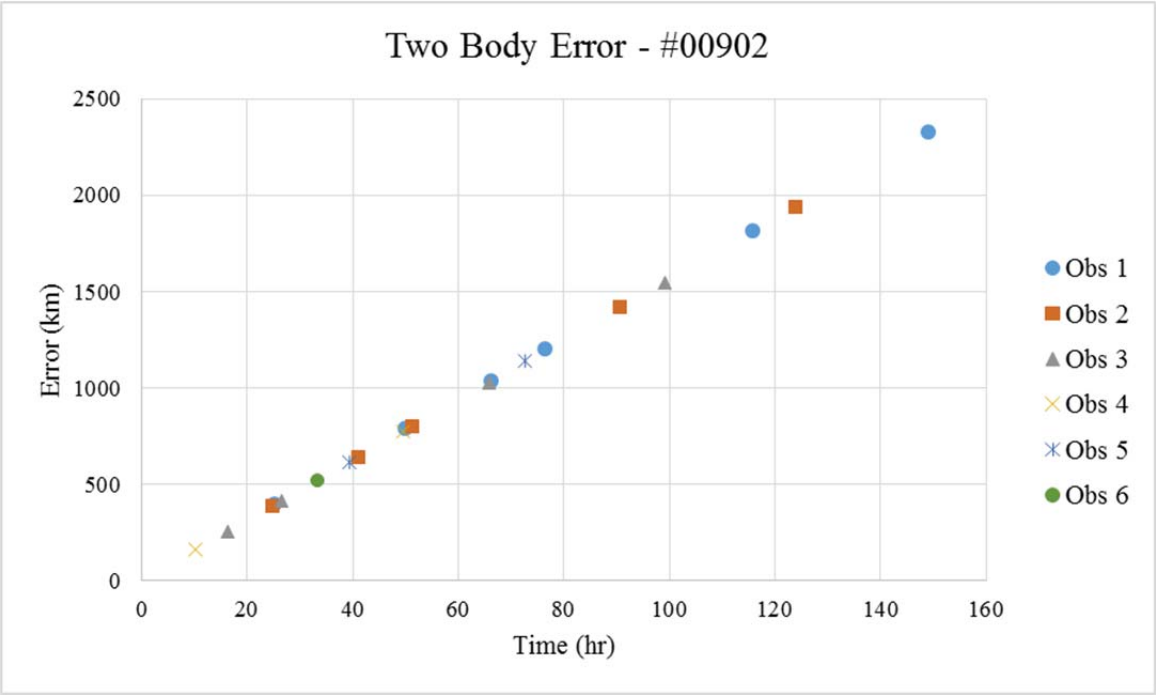

Figure 17. Error of the Two-Body Propagator Over Time–#00902

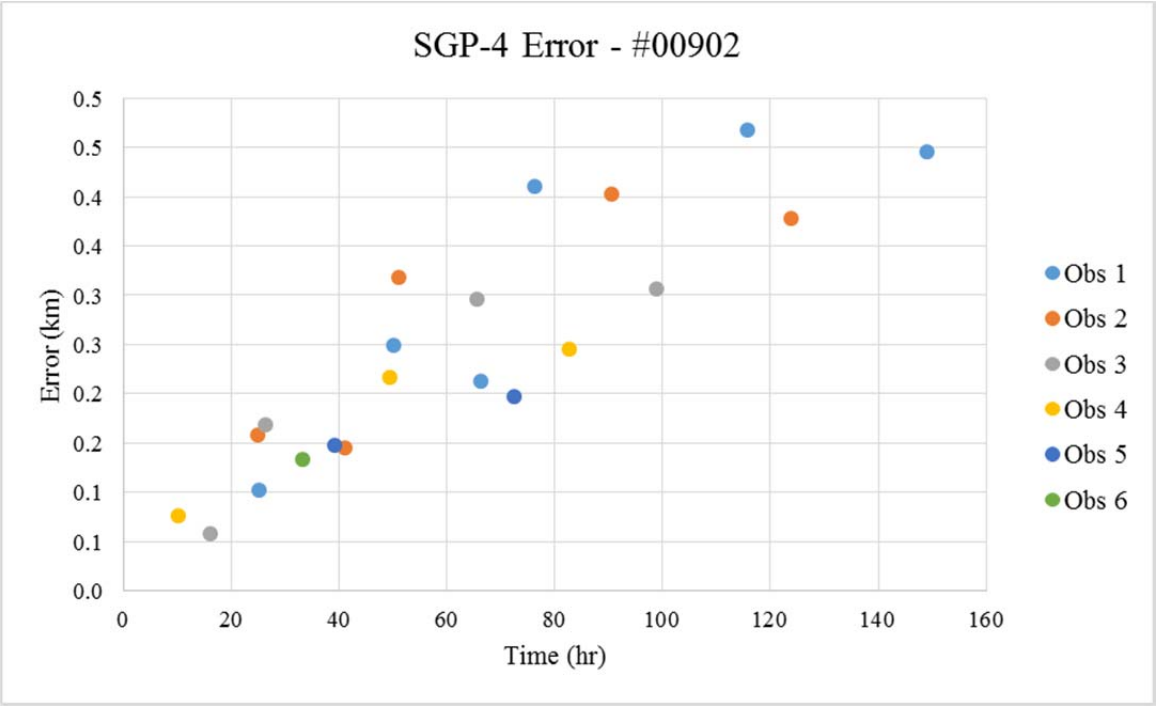

Figure 18. Error of the SGP-4 Propagator Over Time–#00902

J. CATALOG NUMBER 01510–DODECAPOLE 2

This ephemeris data represents one of three samples for semi-major axes 7300–7400 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 28. Two-Line Element for #01510 30NOV–7DEC15

Obs	TLE
1	1 1510U 65065C 15334.86553345 +.00002236 +00000-0 +17421-2 0 9994
	2 1510 090.0293 009.0002 0038914 010.5327 349.6653 13.91729397495326
2	1 1510U 65065C 15337.95710061 +.00001838 +00000-0 +14300-2 0 9997
	2 1510 090.0298 009.0100 0038800 000.4953 359.6253 13.91741102495759
3	1 1510U 65065C 15339.89830377 +.00002006 +00000-0 +15615-2 0 9993
	2 1510 090.0294 009.0161 0038794 354.2734 005.7991 13.91749214496022
4	1 1510U 65065C 15340.97674525 +.00002053 +00000-0 +15983-2 0 9995
	2 1510 090.0294 009.0194 0038777 350.7834 009.2624 13.91753795496178

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 29. Ephemeris Data Derived From TLEs for #01510

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	20 : 46 : 22.090	13.9173	0.0038914	90.0293	10.5327	9.0002	349.6653
2	3-Dec	22 : 58 : 13.493	13.9174	38800	90.0298	0.4953	9.0100	359.6253
3	5-Dec	21 : 33 : 33.446	13.9175	38794	90.0294	354.2734	9.0161	5.7991
4	6-Dec	23 : 26 : 30.790	13.9175	38777	90.0294	350.7834	9.0194	9.2624

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 30. Error of Propagated Ephemeris for #01510

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.138	1207.3056	74.19761
→3	0.239	1953.1637	120.78649
→4	0.436	2362.4494	146.66908
Obs 2→3	0.116	760.484	46.58888
→4	0.297	1179.193	72.47147
Obs 3→4	0.158	424.034	25.88260

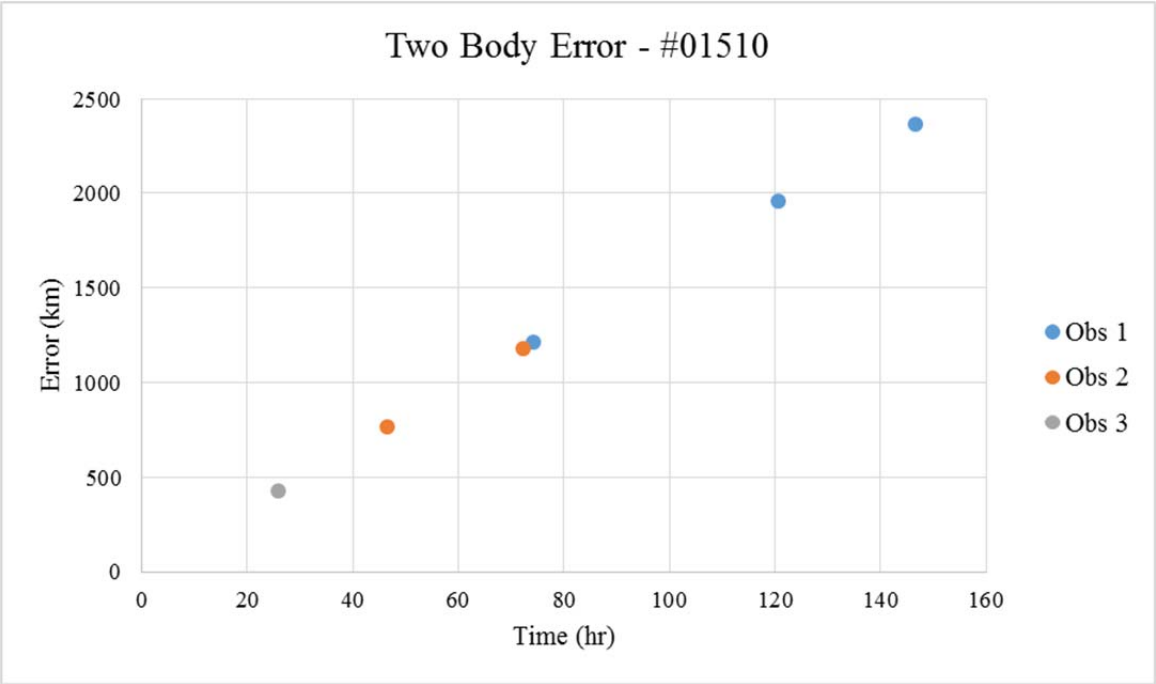

Figure 19. Error of the Two Body Propagator Over Time–#01510

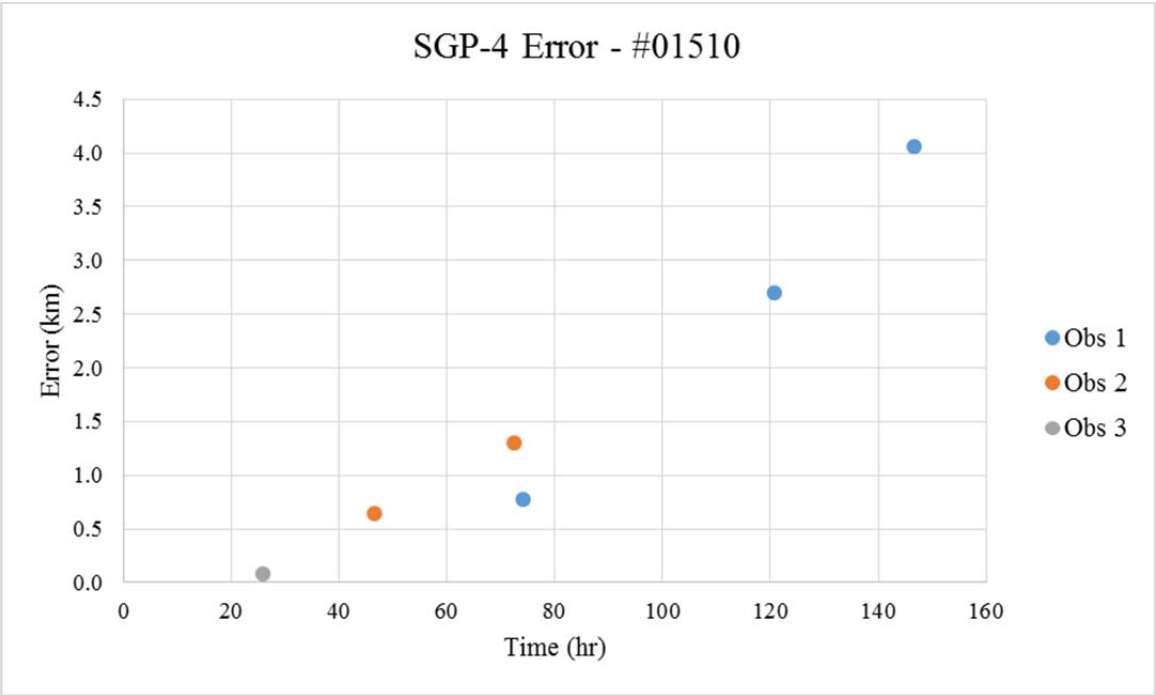

Figure 20. Error of the SGP-4 Propagator Over Time–#01510

K. CATALOG NUMBER 01641–OV2-1

This ephemeris data represents one of three samples for inclinations 30–40 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 31. Two-Line Element for #01641 30NOV–7DEC15

Obs	TLE
1	1 01641U 65082C 15335.40245424 .00000197 00000-0 39159-4 0 9993
	2 01641 32.2980 317.7842 0019352 314.8811 45.0263 14.53068705656754
2	1 01641U 65082C 15337.12005467 .00000176 00000-0 34196-4 0 9998
	2 01641 32.2979 307.7938 0019291 329.9520 30.0018 14.53069109657003
3	1 01641U 65082C 15338.90636003 .00000168 00000-0 32471-4 0 9996
	2 01641 32.2978 297.4039 0019215 345.6710 14.3389 14.53069566657262
4	1 01641U 65082C 15340.21173711 .00000169 00000-0 32695-4 0 9994
	2 01641 32.2977 289.8114 0019144 357.1841 2.8695 14.53069968657453
5	1 01641U 65082C 15341.24229779 .00000184 00000-0 36175-4 0 9998
	2 01641 32.2975 283.8173 0019100 6.3175 353.7709 14.53070347657609

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 32. Ephemeris Data Derived From TLEs for #01641

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	9 : 39 : 32.046	14.5307	0.0019352	32.2980	314.8811	317.7842	45.0263
2	3-Dec	2 : 52 : 52.723	14.5307	19291	32.2979	329.9520	307.7938	30.0018
3	4-Dec	21 : 45 : 9.507	14.5307	19215	32.2978	345.6710	297.4039	14.3389
4	6-Dec	5 : 4 : 54.086	14.5307	19144	32.2977	357.1841	289.8114	2.8695
5	7-Dec	5 : 48 : 54.529	14.5307	19100	32.2975	6.3175	283.8173	353.7709

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 33. Error of Propagated Ephemeris for #01641

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.095	1053	41.22241
→3	0.279	2118	84.09374
→4	0.363	2830	115.42279
→5	0.452	3363	140.15625
Obs 2→3	0.095	1101	42.87133
→4	0.178	1874	74.20038
→5	0.242	2460	98.93383
Obs 3→4	0.104	803	31.32905
→6	0.186	1426	56.06251
Obs 4→5	0.056	635	24.73346

Figure 21. Error of the Two-Body Propagator Over Time–#01641

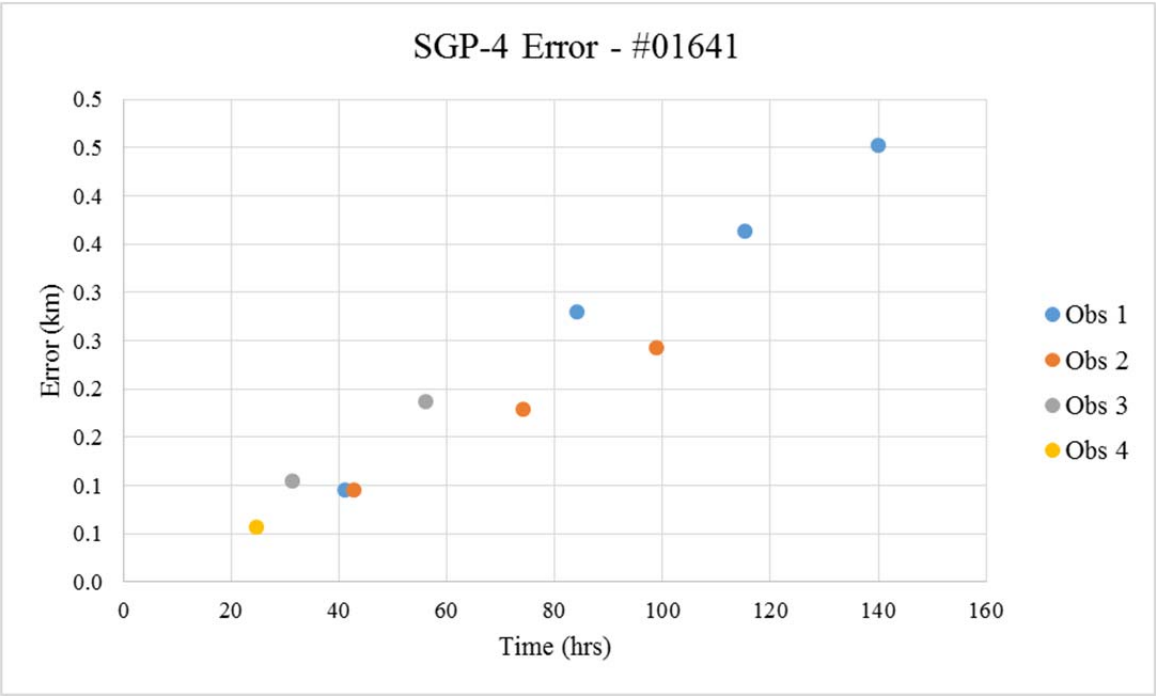

Figure 22. Error of the SGP-4 Propagator Over Time–#01641

L. CATALOG NUMBER 01642–TITAN 3C DEBRIS

This ephemeris data represents one of three samples for inclinations 30–40 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 34. Two-Line Element for #01642 30NOV–7DEC15

Obs	TLE
1	1 1642U 65082D 15334.93827446 +.00000456 +00000-0 +54653-4 0 9995
	2 1642 032.0942 226.8039 0025850 183.7010 176.3450 14.78719025666542
2	1 1642U 65082D 15335.95089259 +.00000439 +00000-0 +52281-4 0 9996
	2 1642 032.0940 220.6545 0025888 193.0688 166.9291 14.78719770666691
3	1 01642U 65082D 15336.08590831 .00000436 00000-0 51986-4 0 9992
	2 01642 32.0940 219.8346 0025892 194.3102 165.6815 14.78719871687930
4	1 1642U 65082D 15336.89600266 +.00000391 +00000-0 +45985-4 0 9997
	2 1642 032.0939 214.9149 0025935 201.7890 158.1657 14.78720253666833
5	1 1642U 65082D 15337.90862077 +.00000344 +00000-0 +39699-4 0 9993
	2 1642 032.0937 208.7653 0025972 211.1230 148.7880 14.78720733666988
6	1 01642U 65082D 15338.78622336 .00000354 00000-0 41004-4 0 9996
	2 01642 32.0936 203.4355 0026002 219.2196 140.6569 14.78721365688333
7	1 1642U 65082D 15338.92123930 +.00000313 +00000-0 +35549-4 0 9990
	2 1642 032.0935 202.6156 0026003 220.4600 139.4115 14.78721212667136
8	1 1642U 65082D 15339.93385823 +.00000360 +00000-0 +41811-4 0 9994
	2 1642 032.0934 196.4658 0026034 229.7934 130.0436 14.78722089667280
9	1 1642U 65082D 15340.94647780 +.00000402 +00000-0 +47342-4 0 9992
	2 1642 032.0933 190.3159 0026064 239.0938 120.7148 14.78722940667438
10	1 1642U 65082D 15341.89159014 +.00000411 +00000-0 +48641-4 0 9998
	2 1642 032.0933 184.5760 0026086 247.7637 112.0244 14.78723582667576

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 35. Ephemeris Data Derived From TLEs for #01642

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22 : 31 : 6.913	14.7872	0.0025850	32.0942	183.7010	226.8039	176.3450
2	1-Dec	22 : 49 : 17.120	14.7872	25888	32.0940	193.0688	220.6545	166.9291
3	2-Dec	2 : 3 : 42.478	14.7872	25892	32.0940	194.3102	219.8346	165.6815
4	2-Dec	21 : 30 : 14.630	14.7872	25935	32.0939	201.7890	214.9149	158.1657
5	3-Dec	21 : 48 : 24.835	14.7872	25972	32.0937	211.1230	208.7653	148.7880
6	4-Dec	18 : 52 : 9.698	14.7872	26002	32.0936	219.2196	203.4355	140.6569
7	4-Dec	22 : 6 : 35.076	14.7872	26003	32.0935	220.4600	202.6156	139.4115
8	5-Dec	22 : 24 : 45.351	14.7872	26034	32.0934	229.7934	196.4658	130.0436
9	6-Dec	22 : 42 : 55.682	14.7872	26064	32.0933	239.0938	190.3159	120.7148
10	7-Dec	21 : 23 : 53.388	14.7872	26086	32.0933	247.7637	184.5760	112.0244

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 36. Error of Propagated Ephemeris for #01642

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.073	649	24.30284
→3	0.071	734	27.54321
→4	0.162	1248	46.98548
→5	0.376	1871	71.28831
→6	0.607	2398	92.35077
→7	0.716	2468	95.59116
→8	1.075	3032	119.89401
→9	1.483	3555	144.19688
→10	1.942	4014	166.87958
Obs 2→3	0.014	87	3.24038
→4	0.071	606	22.68264
→5	0.240	1247	46.98548
→6	0.420	1792	68.04794
→7	0.520	1869	71.28832
→8	0.803	2465	95.59118
→9	1.118	3026	119.89405
→10	1.473	3523	142.57674
Obs 3→4	0.072	520	19.44226
→5	0.244	1162	43.74510
→6	0.420	1709	64.80756
→7	0.520	1787	68.04794
→8	0.797	2387	92.35080
→9	1.103	2953	116.65367
→10	1.448	3454	139.33636

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.081	649	24.30283
→6	0.148	1206	45.36530
→7	0.210	1288	48.60568
→8	0.307	1908	72.90853
→9	0.401	2500	97.21140
→10	0.503	3028	119.89410
Obs 5→6	0.083	563	21.06246
→7	0.067	649	24.30284
→8	0.152	1287	48.60570
→9	0.293	1905	72.90857
→10	0.445	2462	95.59126
Obs 6→7	0.079	87	3.24038
→8	0.102	734	27.54324
→9	0.155	1369	51.84611
→10	0.233	1946	74.52880
Obs 7→8	0.148	648	24.30285
→9	0.378	1286	48.60572
→10	0.632	1865	71.28842
Obs 8→9	0.085	648	24.30287
→10	0.165	1244	46.98557
Obs 9→10	0.109	605	22.68270

Figure 23. Error of the Two-Body Propagator Over Time–#01642

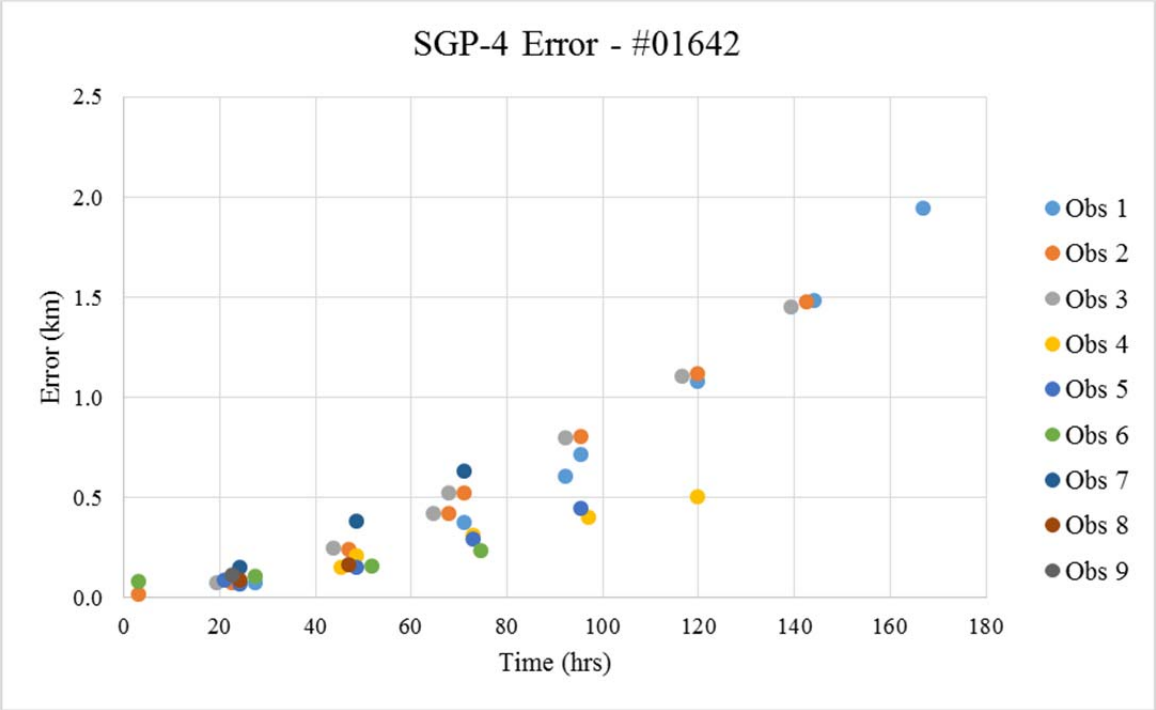

Figure 24. Error of the SGP-4 Propagator Over Time–#01642

M. CATALOG NUMBER 01814–FR 1

This ephemeris data represents one of three samples for inclinations 70–80 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 37. Two-Line Element for #01814 30NOV–7DEC15

Obs	TLE
1	1 01814U 65101A 15335.11426508 .00000479 00000-0 89988-4 0 9997
	2 01814 75.8671 113.0215 0005969 240.8697 119.1885 14.66138058512225
2	1 01814U 65101A 15336.13783858 .00000477 00000-0 89698-4 0 9990
	2 01814 75.8673 111.2708 0005957 238.6065 121.4531 14.66139045512372
3	1 01814U 65101A 15337.77555509 .00000401 00000-0 75922-4 0 9993
	2 01814 75.8675 108.4698 0005931 235.0022 125.0601 14.66140157512617
4	1 01814U 65101A 15338.79912702 .00000388 00000-0 73594-4 0 9995
	2 01814 75.8677 106.7192 0005911 232.6742 127.3899 14.66141045512766
5	1 01814U 65101A 15339.82269824 .00000435 00000-0 82078-4 0 9990
	2 01814 75.8678 104.9686 0005899 230.5247 129.5411 14.66142259512916
6	1 01814U 65101A 15340.84626874 .00000485 00000-0 91209-4 0 9997
	2 01814 75.8680 103.2180 0005880 228.2367 131.8310 14.66143509513067

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 38. Ephemeris Data Derived From TLEs for #01814

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	2 : 44 : 32.503	14.6614	0.0005969	75.8671	240.8697	113.0215	119.1885
2	2-Dec	3 : 18 : 29.253	14.6614	5957	75.8673	238.6065	111.2708	121.4531
3	3-Dec	18 : 36 : 47.960	14.6614	5931	75.8675	235.0022	108.4698	125.0601
4	4-Dec	19 : 10 : 44.575	14.6614	5911	75.8677	232.6742	106.7192	127.3899
5	5-Dec	19 : 44 : 41.128	14.6614	5899	75.8678	230.5247	104.9686	129.5411
6	6-Dec	20 : 18 : 37.619	14.6614	5880	75.8680	228.2367	103.2180	131.8310

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 39. Error of Propagated Ephemeris for #01814

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.083	419	24.56576
→3	0.350	1089	63.87096
→4	0.531	1505	88.43669
→5	0.699	1919	113.00240
→6	0.851	2329	137.56809
Obs 2→3	0.259	670	39.30520
→4	0.427	1088	63.87092
→5	0.580	1503	88.43663
→6	0.715	1917	113.00232
Obs 3→4	0.123	418	24.56573
→5	0.327	836	49.13144
→6	0.615	1252	73.69713
Obs 4→5	0.200	418	24.56571
→6	0.494	835	49.13140
Obs 5→6	0.113	418	24.56569

Figure 25. Error of the Two-Body Propagator Over Time–#01814

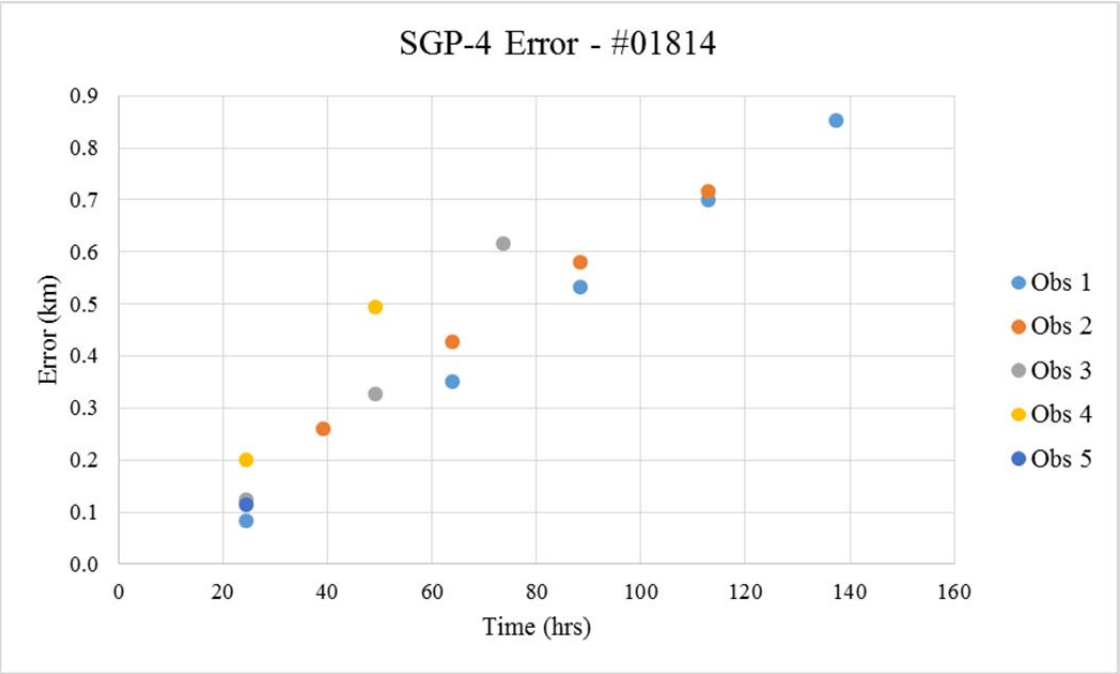

Figure 26. Error of the SGP-4 Propagator Over Time–#01814

N. CATALOG NUMBER 01942–THOR ABLESTAR DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.03-0.04 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 40. Two-Line Element for #01942 30NOV–7DEC15

Obs	TLE
1	1 1942U 61015HS 15334.46976064 +.00000414 +00000-0 +99130-3 0 9991
	2 1942 067.2538 144.2746 0351698 021.1883 009.6454 13.10666850611734
2	1 1942U 61015HS 15335.94841265 +.00000416 +00000-0 +99620-3 0 9995
	2 1942 067.2540 141.1821 0351745 020.1522 146.5410 13.10668098611929
3	1 1942U 61015HS 15336.93876947 +.00000406 +00000-0 +97429-3 0 9994
	2 1942 067.2542 139.1110 0351801 019.4653 139.4528 13.10668856612056
4	1 1942U 61015HS 15337.52742030 +.00000402 +00000-0 +96777-3 0 9996
	2 1942 067.2543 137.8800 0351886 019.0776 036.9305 13.10669317612139
5	1 1942U 61015HS 15339.91469841 +.00000408 +00000-0 +98020-3 0 9996
	2 1942 067.2548 132.8875 0351989 017.4050 141.1250 13.10671281612447
6	1 1942U 61015HS 15340.74383155 +.00000386 +00000-0 +93380-3 0 9991
	2 1942 067.2548 131.1533 0352017 016.8201 093.3344 13.10671723612559

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 41. Ephemeris Data Derived From TLEs for #01942

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	11 : 16 : 27.319	13.1067	0.0351698	67.2538	21.1883	144.2746	9.6454
2	1-Dec	22 : 45 : 42.853	13.1067	351745	67.2540	20.1522	141.1821	146.5410
3	2-Dec	22 : 31 : 49.682	13.1067	351801	67.2542	19.4653	139.1110	139.4528
4	3-Dec	12 : 39 : 29.114	13.1067	351886	67.2543	19.0776	137.8800	36.9305
5	5-Dec	21 : 57 : 9.943	13.1067	351989	67.2548	17.4050	132.8875	141.1250
6	6-Dec	17 : 51 : 7.046	13.1067	352017	67.2548	16.8201	131.1533	93.3344

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 42. Error of Propagated Ephemeris for #01942

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.391	486	35.48765
→3	0.650	790	59.25621
→4	0.569	716	73.38383
→5	1.973	1756	130.67851
→6	2.180	1433	150.57770
Obs 2→3	0.214	316	23.76856
→4	0.397	372	37.89618
→5	1.330	1278	95.19086
→6	1.645	1092	115.09005
Obs 3→4	0.227	139	14.12762
→5	0.813	958	71.42229
→6	1.095	864	91.32149
Obs 4→5	0.750	768	57.29467
→6	0.949	730	77.19387
Obs 5→6	0.378	189	19.89920

Figure 27. Error of the Two-Body Propagator Over Time–#01942

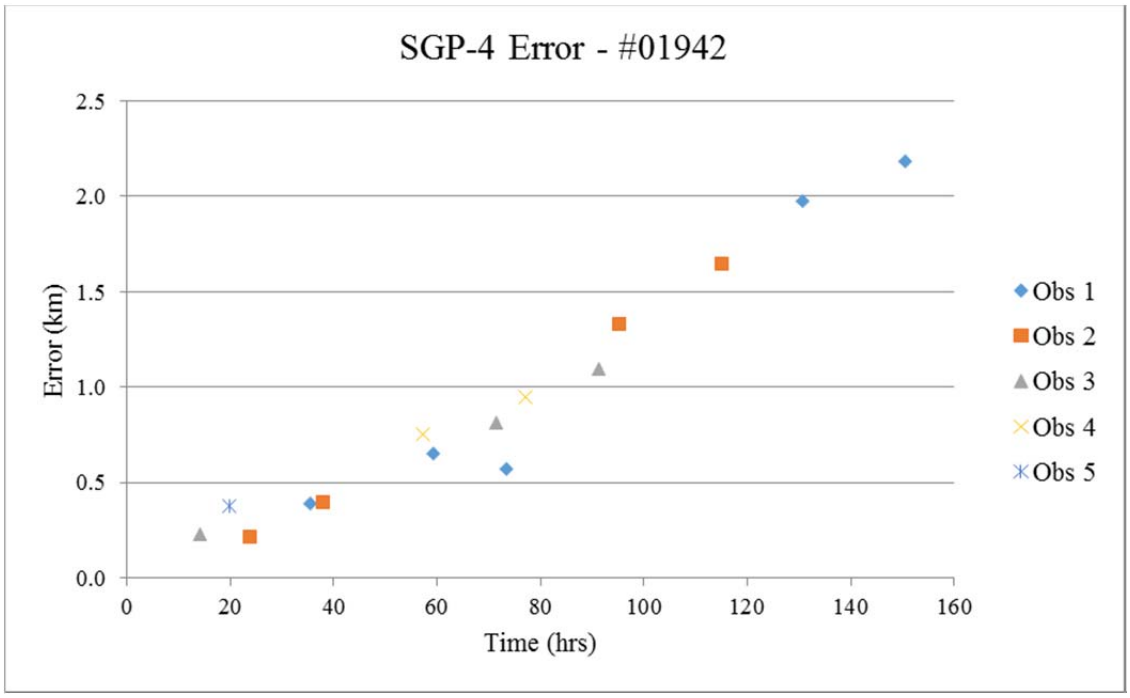

Figure 28. Error of the SGP-4 Propagator Over Time–#01942

O. CATALOG NUMBER 02088–SCOUT X-4 DEBRIS

This ephemeris data represents one of three samples for inclinations 50–60 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 43. Two-Line Element for #02088 30NOV–7DEC15

Obs	TLE
1	1 2088U 65093D 15334.83006059 +.00000691 +00000-0 +19310-3 0 9991 2 2088 059.7199 264.3977 0094099 067.5501 293.5475 14.53562555593141
2	1 2088U 65093D 15335.86182682 +.00000582 +00000-0 +16843-3 0 9999 2 2088 059.7199 260.8224 0094169 068.4228 292.6818 14.53563513593293
3	1 02088U 65093D 15336.75602316 .00000509 00000-0 15216-3 0 9991 2 02088 59.7199 257.7238 0094226 69.1779 291.9326 14.53564484614205
4	1 2088U 65093D 15336.89359177 +.00000496 +00000-0 +14928-3 0 9994 2 2088 059.7199 257.2471 0094236 069.2961 291.8153 14.53564626593441
5	1 2088U 65093D 15337.03116037 +.00000494 +00000-0 +14865-3 0 9995 2 2088 059.7199 256.7704 0094245 069.4117 291.7005 14.53564797593465
6	1 2088U 65093D 15338.95711893 +.00000376 +00000-0 +12231-3 0 9992 2 2088 059.7198 250.0967 0094371 071.0364 290.0878 14.53566865593744
7	1 2088U 65093D 15339.92009692 +.00000448 +00000-0 +13842-3 0 9996 2 2088 059.7197 246.7598 0094437 071.8502 289.2797 14.53568511593885
8	1 2088U 65093D 15340.95185790 +.00000509 +00000-0 +15214-3 0 9998 2 2088 059.7196 243.1845 0094469 072.7387 288.3967 14.53570170594037
9	1 02088U 65093D 15341.02064195 .00000506 00000-0 15150-3 0 9998 2 02088 59.7196 242.9461 0094463 72.7961 288.3396 14.53570223614825

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 44. Ephemeris Data Derived From TLEs for #02088

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	19 : 55 : 17.235	14.5356	0.0094099	59.7199	67.5501	264.3977	293.5475
2	1-Dec	20 : 41 : 1.837	14.5356	94169	59.7199	68.4228	260.8224	292.6818
3	2-Dec	18 : 8 : 40.401	14.5356	94226	59.7199	69.1779	257.7238	291.9326
4	2-Dec	21 : 26 : 46.329	14.5356	94236	59.7199	69.2961	257.2471	291.8153
5	3-Dec	0 : 44 : 52.256	14.5356	94245	59.7199	69.4117	256.7704	291.7005
6	4-Dec	22 : 58 : 15.076	14.5357	94371	59.7198	71.0364	250.0967	290.0878
7	5-Dec	22 : 4 : 56.374	14.5357	94437	59.7197	71.8502	246.7598	289.2797
8	6-Dec	22 : 50 : 40.523	14.5357	94469	59.7196	72.7387	243.1845	288.3967
9	7-Dec	0 : 29 : 43.464	14.5357	94463	59.7196	72.7961	242.9461	288.3396

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 45. Error of Propagated Ephemeris for #02088

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.498	395	24.76239
→3	0.940	735	46.22310
→4	1.029	788	49.52475
→5	1.136	840	52.82639
→6	2.807	1573	99.04940
→7	3.978	1932	122.16087
→8	5.257	2321	146.92314
→9	5.365	2346	148.57395
Obs 2→3	0.118	342	21.46071
→4	0.142	394	24.76236
→5	0.178	446	28.06401
→6	0.758	1181	74.28701
→7	1.229	1543	97.39848
→8	1.673	1933	122.16075
→9	1.721	1959	123.81156
Obs 3→4	0.014	53	3.30165
→5	0.033	105	6.60329
→6	0.270	840	52.82630
→7	0.428	1204	75.93777
→8	0.525	1596	100.70003
→9	0.541	1622	102.35085
Obs 4→5	0.019	53	3.30165
→6	0.241	788	49.52465
→7	0.368	1152	72.63612
→8	0.456	1544	97.39839
→9	0.467	1570	99.04920
Obs 5→6	0.222	736	46.22301
→7	0.342	1100	69.33448
→8	0.435	1492	94.09674
→9	0.445	1518	95.74756
Obs 6→7	0.238	368	23.11147
→8	0.681	763	47.87374
→9	0.703	789	49.52455
Obs 7→8	0.160	395	24.76226
→9	0.165	421	26.41308
Obs 8→9	0.017	26	1.65082

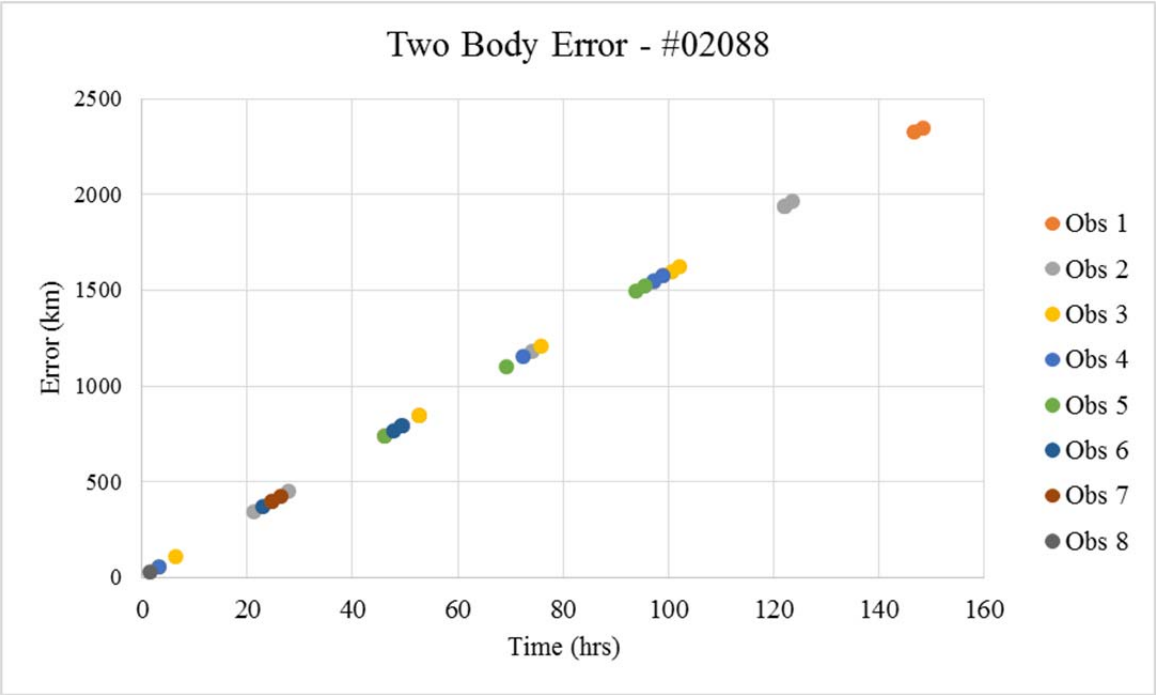

Figure 29. Error of the Two-Body Propagator Over Time–#02088

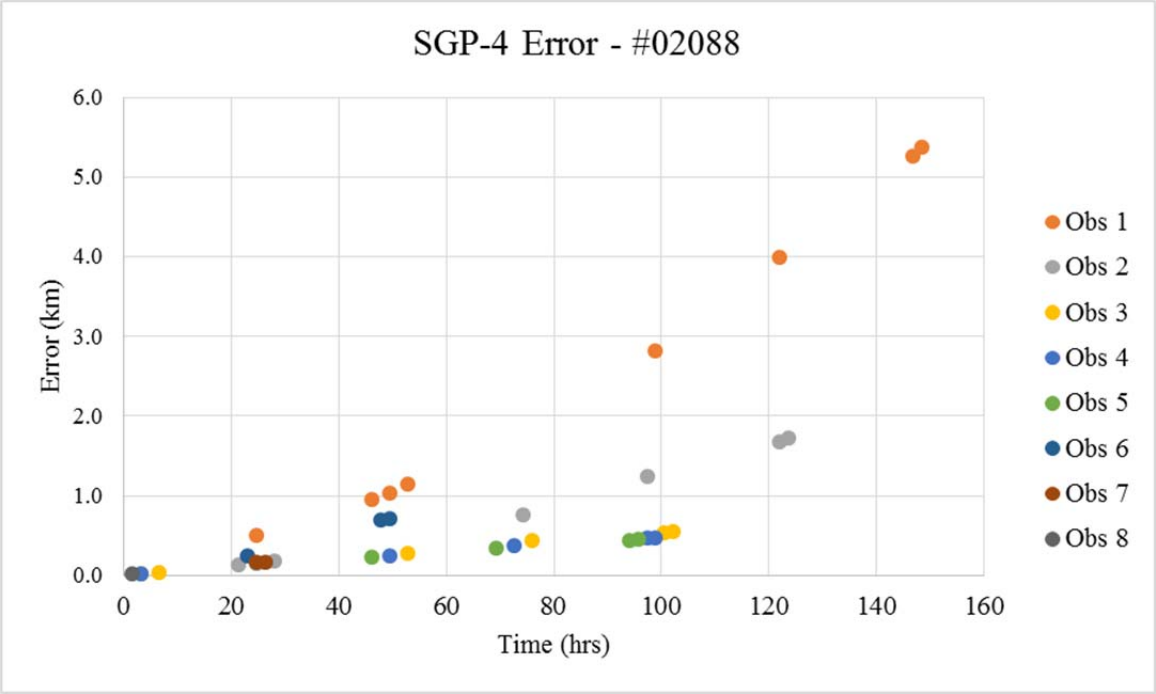

Figure 30. Error of the SGP-4 Propagator Over Time–#02088

P. CATALOG NUMBER 02176–TRANSIT 13

This ephemeris data represents one of three samples for semi-major axes 7200–7300 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 46. Two-Line Element for #02176 30NOV–7DEC15

Obs	TLE
1	1 02176U 66041A 15335.40569986 .00000178 00000-0 10544-3 0 9990
	2 02176 90.1413 7.0445 0076924 39.7914 320.8872 14.02719449527912
2	1 02176U 66041A 15336.54704692 .00000166 00000-0 98246-4 0 9994
	2 02176 90.1413 7.0622 0076769 36.2491 324.3856 14.02719798528074
3	1 02176U 66041A 15337.61705932 .00000156 00000-0 91553-4 0 9994
	2 02176 90.1412 7.0787 0076633 32.9173 327.6745 14.02720052528219
4	1 02176U 66041A 15339.11507579 .00000153 00000-0 89961-4 0 9995
	2 02176 90.1411 7.1019 0076437 28.2553 332.2741 14.02720456528428
5	1 02176U 66041A 15340.54175699 .00000209 00000-0 12517-3 0 9992
	2 02176 90.1409 7.1239 0076251 23.8249 336.6430 14.02721225528626
6	1 02176U 66041A 15341.68310144 .00000215 00000-0 12920-3 0 9999
	2 02176 90.1407 7.1414 0076108 20.2780 340.1394 14.02721632528789

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 47. Ephemeris Data Derived From TLEs for #02176

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	9 : 44 : 12.468	14.0272	0.0076924	90.1413	39.7914	7.0445	320.8872
2	2-Dec	13 : 7 : 44.854	14.0272	76769	90.1413	36.2491	7.0622	324.3856
3	3-Dec	14 : 48 : 33.925	14.0272	76633	90.1412	32.9173	7.0787	327.6745
4	5-Dec	2 : 45 : 42.548	14.0272	76437	90.1411	28.2553	7.1019	332.2741
5	6-Dec	13 : 0 : 7.804	14.0272	76251	90.1409	23.8249	7.1239	336.6430
6	7-Dec	16 : 23 : 39.964	14.0272	76108	90.1407	20.2780	7.1414	340.1394

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 48. Error of Propagated Ephemeris for #02176

	Error (km)		Elapsed
	SGP-4	**Two Body**	**Time (hr)**
Obs 1→2	0.138	455	27.39233
→3	0.239	880	53.07263
→4	0.436	1474	89.02502
→5	0.619	2036	123.26537
→6	0.777	2484	150.65764
Obs 2→3	0.116	426	25.68030
→4	0.297	1021	61.63269
→5	0.443	1586	95.87304
→6	0.567	2035	123.26531
Obs 3→4	0.158	596	35.95240
→5	0.328	1162	70.19274
→6	0.461	1613	97.58501
Obs 4→5	0.226	567	34.24035
→6	0.374	1019	61.63262
Obs 5→6	0.175	453	27.39227

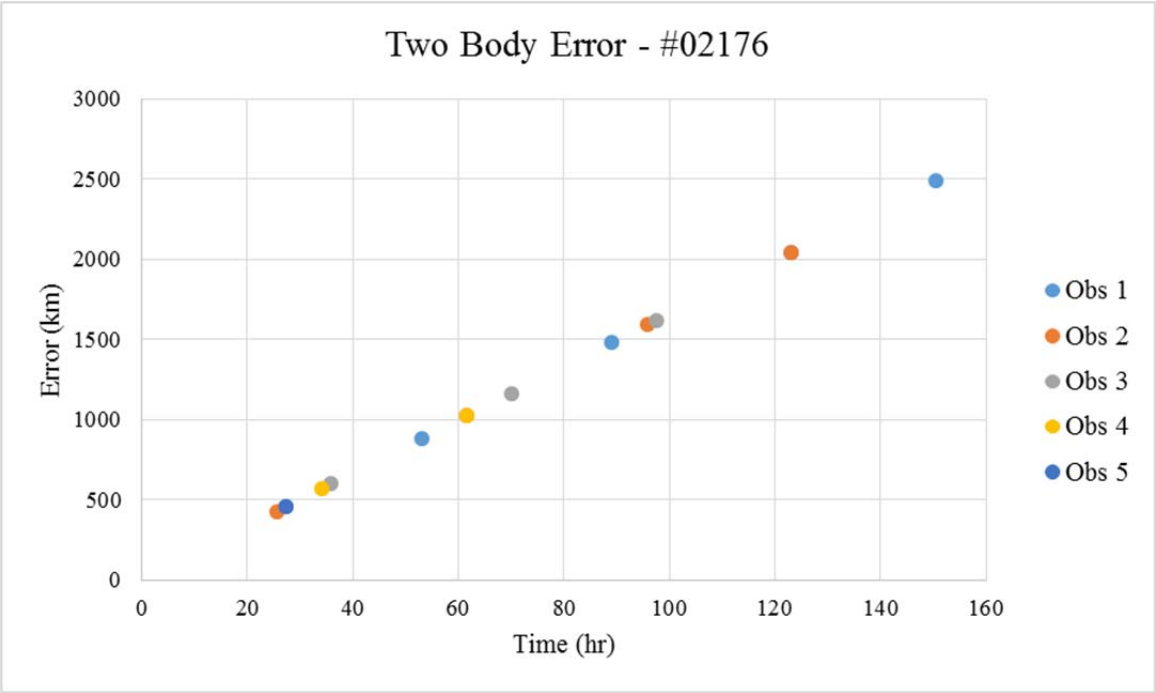

Figure 31. Error of the Two-Body Propagator Over Time–#02176

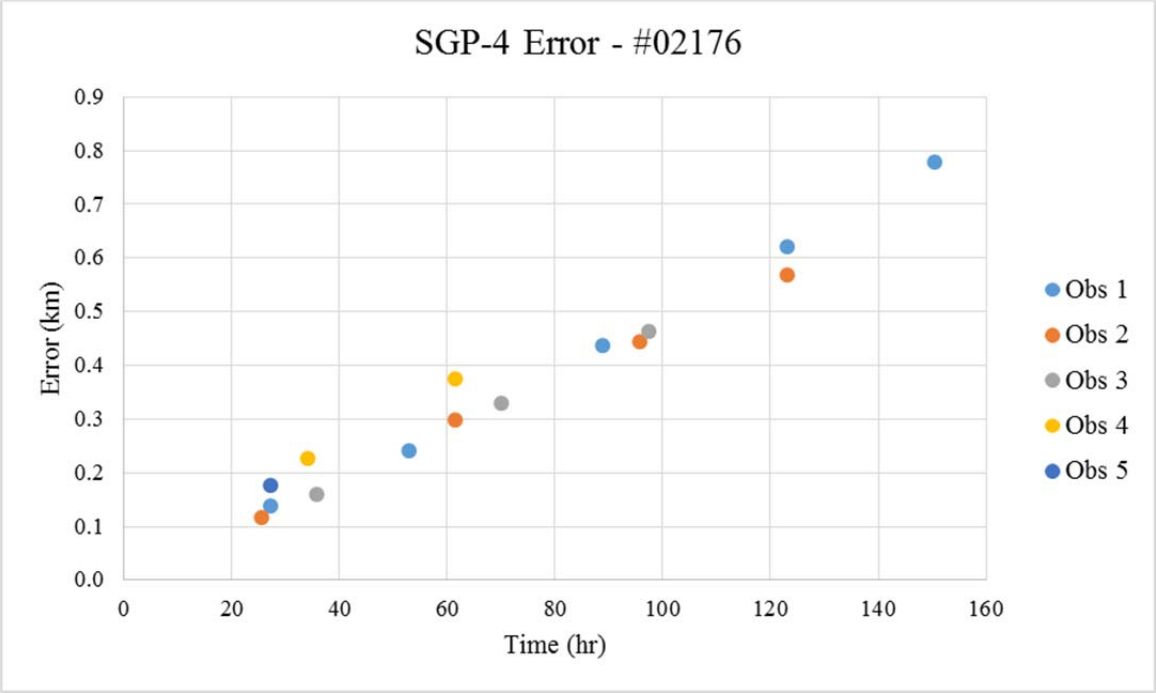

Figure 32. Error of the SGP-4 Propagator Over Time–#02176

Q. CATALOG NUMBER 03557–COSMOS 252 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.08-0.09 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 49. Two-Line Element for #03557 30NOV–7DEC15

Obs	TLE
1	1 3557U 68097K 15334.89393694 +.00000701 +00000-0 +25173-3 0 9996
	2 3557 062.3014 157.8728 0875216 123.3917 245.3958 13.19479536245523
2	1 3557U 68097K 15335.57598921 +.00000775 +00000-0 +27411-3 0 9990
	2 3557 062.3014 156.1080 0875188 123.5402 245.2334 13.19480963245618
3	1 3557U 68097K 15336.94009195 +.00000732 +00000-0 +26131-3 0 9993
	2 3557 062.3014 152.5784 0875102 123.8339 244.9119 13.19483068245792
4	1 03557U 68097K 15337.09165881 .00000724 00000-0 25877-3 0 9992
	2 03557 62.3014 152.1861 0875095 123.8656 244.8772 13.19483294246276
5	1 3557U 68097K 15337.92527577 +.00000624 +00000-0 +22858-3 0 9993
	2 3557 062.3014 150.0291 0875055 124.0456 244.6801 13.19484289245924
6	1 3557U 68097K 15338.91045815 +.00000529 +00000-0 +19960-3 0 9997
	2 3557 062.3015 147.4801 0874999 124.2588 244.4465 13.19485630246056
7	1 03557U 68097K 15339.51672381 .00000559 00000-0 20886-3 0 9990
	2 03557 62.3016 145.9116 0874981 124.3883 244.3047 13.19486893246595
8	1 3557U 68097K 15339.89563949 +.00000517 +00000-0 +19621-3 0 9999
	2 3557 062.3017 144.9312 0874952 124.4704 244.2146 13.19487348246184

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 50. Ephemeris Data Derived From TLEs for #03557

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 27 : 16.152	13.1948	0.0875216	62.3014	123.3917	157.8728	245.3958
2	1-Dec	13 : 49 : 25.468	13.1948	875188	62.3014	123.5402	156.1080	245.2334
3	2-Dec	22 : 33 : 43.944	13.1948	875102	62.3014	123.8339	152.5784	244.9119
4	3-Dec	2 : 11 : 59.321	13.1948	875095	62.3014	123.8656	152.1861	244.8772
5	3-Dec	22 : 12 : 23.827	13.1948	875055	62.3014	124.0456	150.0291	244.6801
6	4-Dec	21 : 51 : 3.584	13.1949	874999	62.3015	124.2588	147.4801	244.4465
7	5-Dec	12 : 24 : 4.937	13.1949	874981	62.3016	124.3883	145.9116	244.3047
8	5-Dec	21 : 29 : 43.252	13.1949	874952	62.3017	124.4704	144.9312	244.2146

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 51. Error of Propagated Ephemeris for #03557

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.128	234	16.36925
→3	0.414	703	49.10772
→4	0.422	756	52.74532
→5	0.618	1040	72.75213
→6	0.942	1376	96.39651
→7	1.031	1583	110.94688
→8	1.129	1715	120.04086
Obs 2→3	0.117	469	32.73847
→4	0.147	521	36.37607
→5	0.218	806	56.38288
→6	0.273	1142	80.02725
→7	0.363	1350	94.57763
→8	0.416	1482	103.67161
Obs 3→4	0.033	52	3.63760
→5	0.141	338	23.64441
→6	0.358	675	47.28879
→7	0.38	883	61.83916
→8	0.437	1014	70.93314
Obs 4→5	0.145	286	20.00681
→6	0.394	623	43.65118
→7	0.431	831	58.20156
→8	0.502	962	67.29554
Obs 5→6	0.484	337	23.64438
→7	0.702	545	38.19475
→8	0.906	676	47.28873
Obs 6→7	0.276	209	14.55038
→8	0.536	340	23.64435
Obs 7→8	0.183	131	9.09398

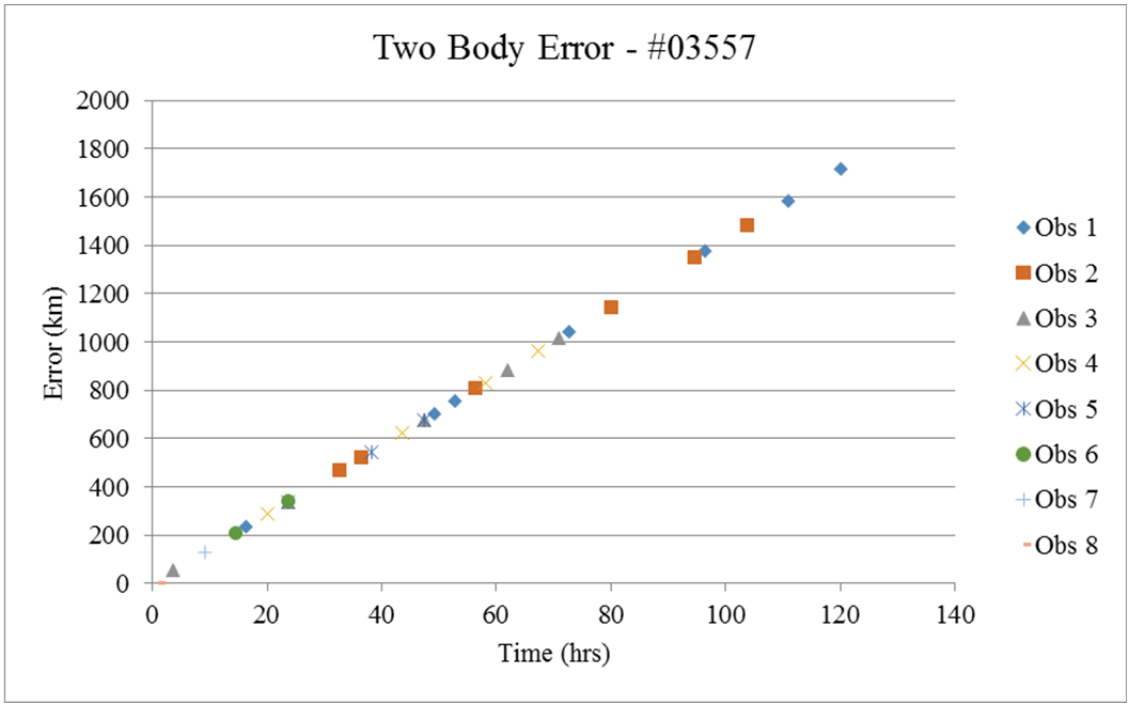

Figure 33. Error of the Two-Body Propagator Over Time–#03557

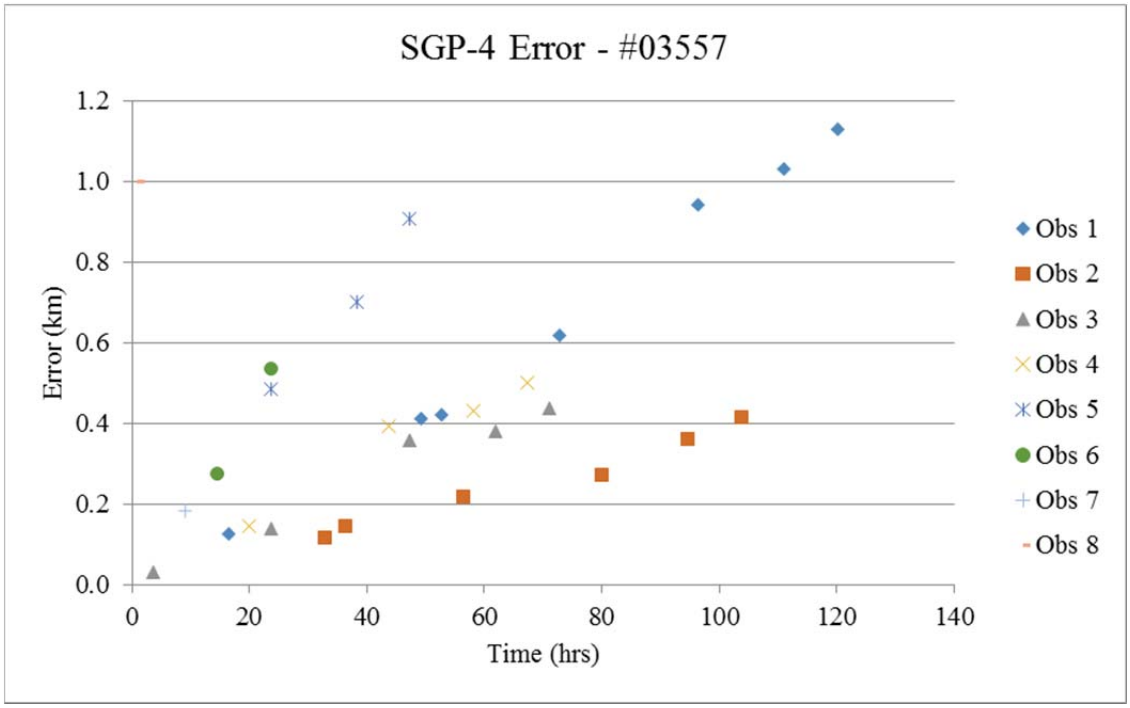

Figure 34. Error of the SGP-4 Propagator Over Time–#03557

R. CATALOG NUMBER 03784–COSMOS 252 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.06-0.07 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 52. Two-Line Element for #03784 30NOV–7DEC15

Obs	TLE
1	1 3784U 68097AW 15334.46860158 +.00000971 +00000-0 +79683-3 0 9999 2 3784 062.2559 346.5217 0651804 244.3822 108.8473 13.23491108558810
2	1 3784U 68097AW 15343.91277786 +.00000512 +00000-0 +45434-3 0 9996 2 3784 062.2562 322.0385 0650989 246.6898 106.4339 13.23507318560066
3	1 03784U 68097AW 15338.01962569 .00000579 00000-0 50411-3 0 9995 2 03784 62.2560 337.3160 0651544 245.2552 107.9324 13.23496906578197
4	1 03784U 68097AW 15339.37958836 .00000688 00000-0 58612-3 0 9999 2 03784 62.2556 333.7903 0651351 245.5814 107.5919 13.23499867578372
5	1 03784U 68097AW 15343.91277786 .00000512 00000-0 45434-3 0 9996 2 03784 62.2562 322.0385 0650989 246.6898 106.4339 13.23507318578975

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 53. Ephemeris Data Derived From TLEs for #03784

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	11 : 14 : 47.177	13.2349	0.0651804	62.2559	244.3822	346.5217	108.8473
2	4-Dec	0 : 28 : 15.660	13.2350	651544	62.2560	245.2552	337.3160	107.9324
3	5-Dec	9 : 6 : 36.434	13.2350	651351	62.2556	245.5814	333.7903	107.5919
4	9-Dec	21 : 54 : 24.007	13.2351	650989	62.2562	246.6898	322.0385	106.4339
5	10-Dec	23 : 17 : 32.753	13.2351	650818	62.2558	246.9429	319.2964	106.1708

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 54. Error of Propagated Ephemeris for #03784

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.756	1189	85.22458
→3	0.969	1639	117.86368
→4	4.014	3126	226.66023
→5	5.147	3464	252.04599
Obs 2→3	0.809	456	32.63910
→4	7.287	1967	141.43565
→5	9.492	2313	166.82141
Obs 3→4	3.092	1514	108.79655
→5	4.197	1866	134.18231
Obs 4→5	1.055	354	25.38576

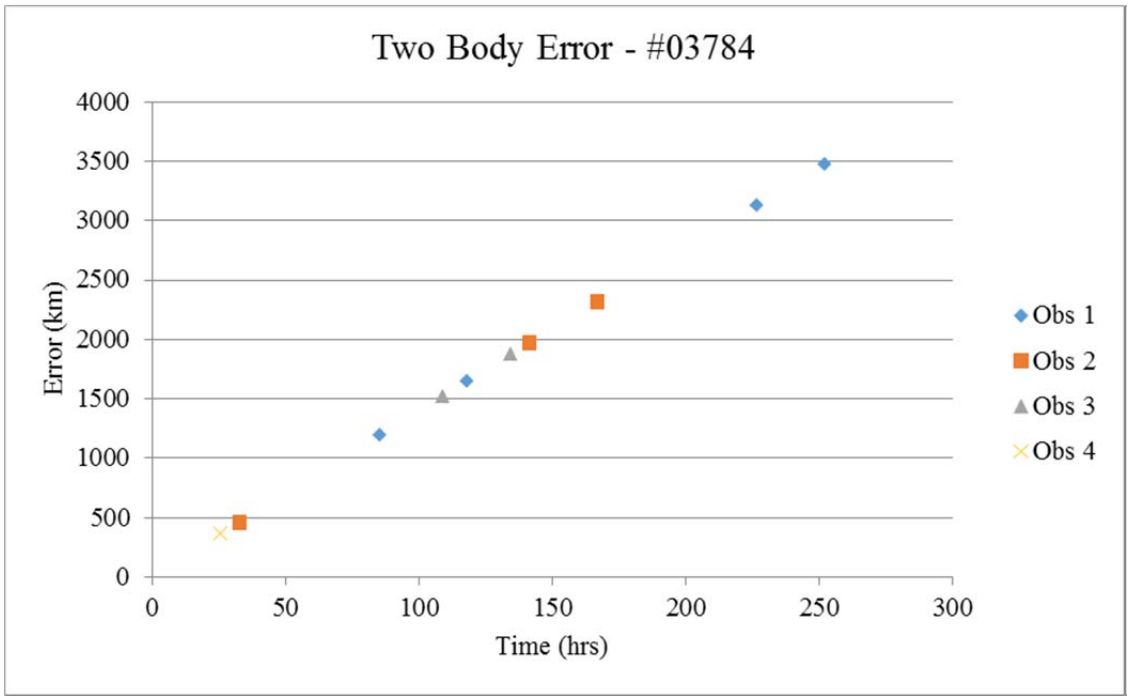

Figure 35. Error of the Two-Body Propagator Over Time–#03784

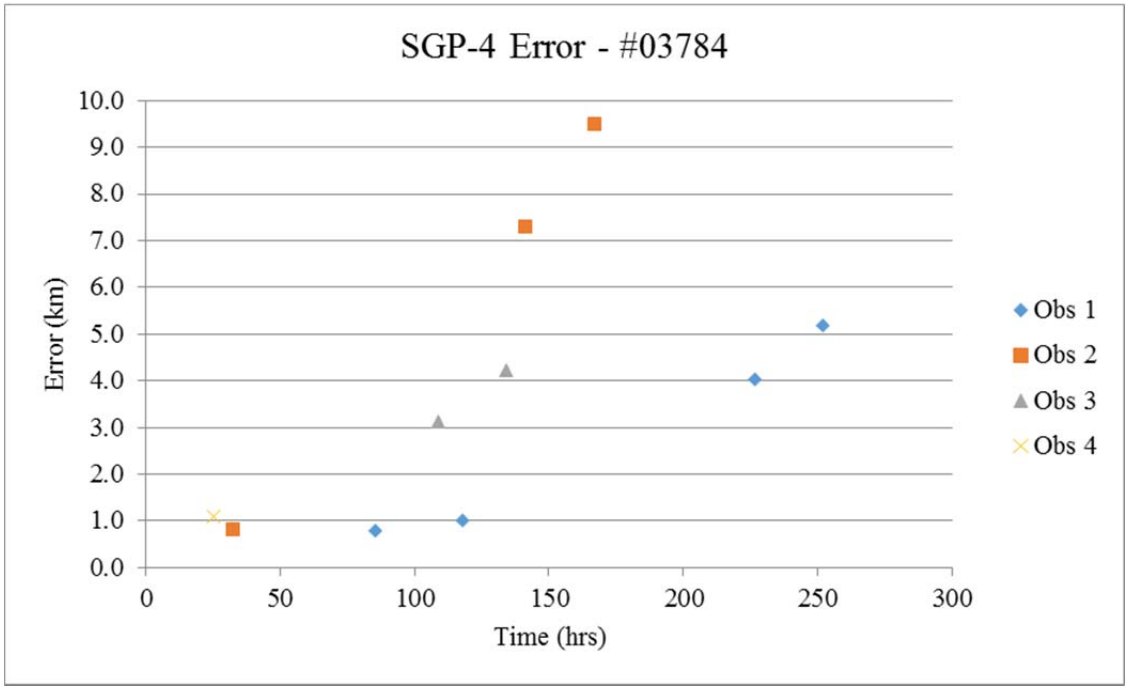

Figure 36. Error of the SGP-4 Propagator Over Time–#03784

S. CATALOG NUMBER 03794–COSMOS 249 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.06-0.07 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 55. Two-Line Element for #03794 30NOV–7DEC15

Obs	TLE
1	1 3794U 68091BB 15337.75125337 +.00001100 +00000-0 +10235-2 0 9994 2 3794 062.2668 104.6428 0668562 102.9050 264.7445 13.14266150202498
2	1 3794U 68091BB 15339.72944282 +.00001255 +00000-0 +11574-2 0 9999 2 3794 062.2672 099.5984 0668252 103.3362 264.2995 13.14271994202755
3	1 3794U 68091BB 15340.71853507 +.00001384 +00000-0 +12696-2 0 9998 2 3794 062.2676 097.0764 0668088 103.5513 264.0772 13.14274766202880
4	1 3794U 68091BB 15341.70762501 +.00001323 +00000-0 +12173-2 0 9994 2 3794 062.2678 094.5539 0667874 103.7670 263.8536 13.14277103203011
5	1 03794U 68091BB 15334.86003851 .00002016 00000-0 18078-2 0 9999 2 03794 62.2667 112.0157 0669022 102.2752 265.3939 13.14259424202775
6	1 03794U 68091BB 15336.76215554 .00001308 00000-0 12018-2 0 9996 2 03794 62.2666 107.1651 0668692 102.6881 264.9679 13.14263879203021
7	1 03794U 68091BB 15338.74034903 .00001036 00000-0 96918-3 0 9993 2 03794 62.2669 102.1203 0668417 103.1212 264.5215 13.14268704203283
8	1 03794U 68091BB 15340.49028323 .00001321 00000-0 12151-2 0 9990 2 03794 62.2674 97.6581 0668120 103.5015 264.1285 13.14274002203519
9	1 03794U 68091BB 15341.55545734 .00001364 00000-0 12526-2 0 9991 2 03794 62.2678 94.9420 0667914 103.7342 263.8876 13.14276893203657

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 56. Ephemeris Data Derived From TLEs for #03794

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	20 : 38 : 27.327	13.1426	0.0669022	62.2667	102.2752	112.0157	265.3939
2	2-Dec	18 : 17 : 30.239	13.1426	668692	62.2666	102.6881	107.1651	264.9679
3	3-Dec	18 : 1 : 48.291	13.1427	668562	62.2668	102.9050	104.6428	264.7445
4	4-Dec	17 : 46 : 6.156	13.1427	668417	62.2669	103.1212	102.1203	264.5215
5	5-Dec	17 : 30 : 23.860	13.1427	668252	62.2672	103.3362	99.5984	264.2995
6	6-Dec	11 : 46 : 0.471	13.1427	668120	62.2674	103.5015	97.6581	264.1285
7	6-Dec	17 : 14 : 41.430	13.1427	668088	62.2676	103.5513	97.0764	264.0772
8	7-Dec	13 : 19 : 51.514	13.1428	667914	62.2678	103.7342	94.9420	263.8876
9	7-Dec	16 : 58 : 58.801	13.1428	667874	62.2678	103.7670	94.5539	263.8536

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 57. Error of Propagated Ephemeris for #03794

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	1.515	624	45.65081
→3	3.283	949	69.38916
→4	5.680	1270	93.12745
→5	8.825	1593	116.86570
→6	12.031	1839	135.12587
→7	12.990	1916	140.60392
→8	16.876	2187	160.69005
→9	17.654	2236	164.34208
Obs 2→3	0.231	324	23.73835
→4	0.495	647	47.47664
→5	0.648	971	71.21489
→6	0.470	1217	89.47506
→7	0.459	1294	94.95311
→8	0.457	1566	115.03924
→9	0.409	1616	118.69127
Obs 3→4	0.590	325	23.73830
→5	1.266	650	47.47655
→6	1.594	899	65.73672
→7	1.760	976	71.21476
→8	2.469	1250	91.30090
→9	2.532	1300	94.95292
Obs 4→5	0.622	325	23.73825
→6	0.941	574	41.99842
→7	1.119	650	47.47646
→8	1.874	925	67.56260
→9	1.951	975	71.21462
Obs 5→6	0.139	250	18.26017
→7	0.111	325	23.73821
→8	0.127	600	43.82435
→9	0.154	650	47.47637
Obs 6→7	0.052	75	5.47804
→8	0.142	350	25.56418
→9	0.104	400	29.21620
Obs 7→8	0.080	274	20.08613
→9	0.111	324	23.73816
Obs 8→9	0.057	50	3.65202

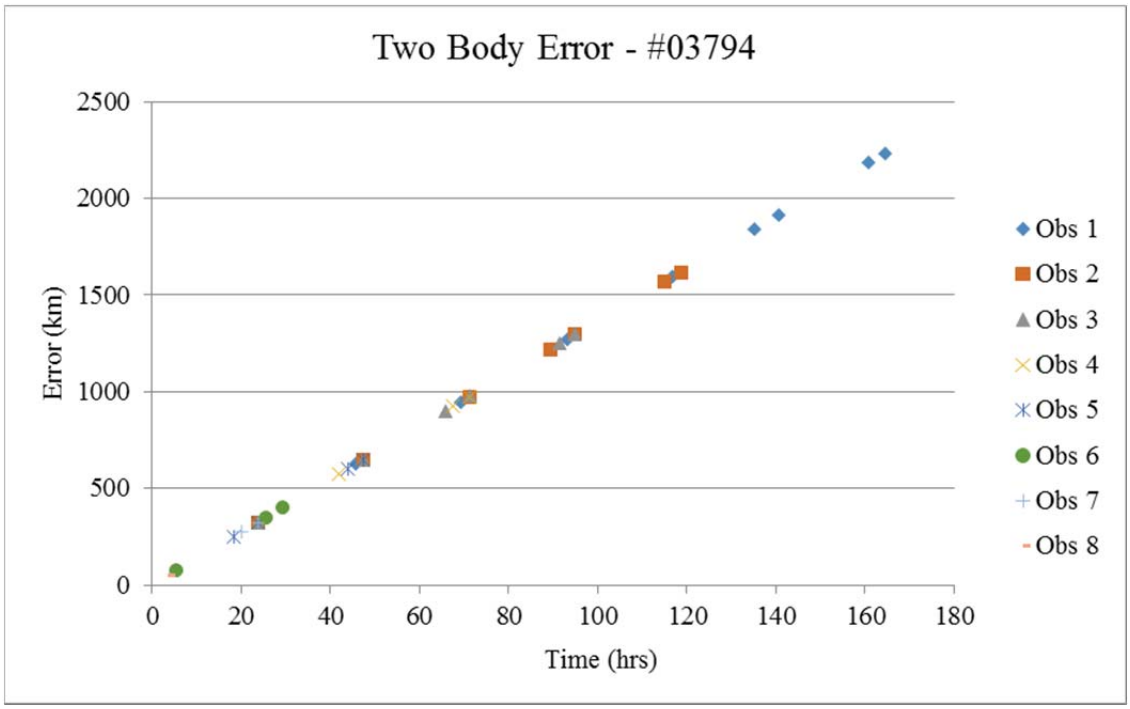

Figure 37. Error of the Two-Body Propagator Over Time–#03794

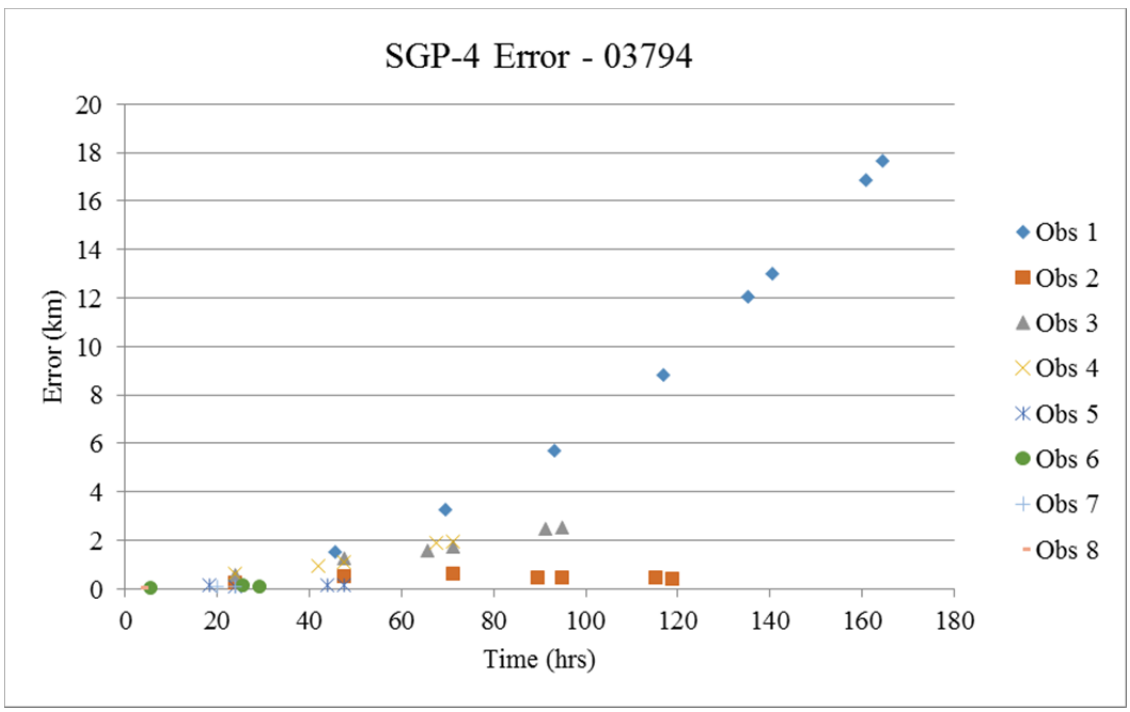

Figure 38. Error of the SGP-4 Propagator Over Time–#03794

T. CATALOG NUMBER 03908–COSMOS 249 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.02-0.03 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 58. Two-Line Element for #03908 30NOV–7DEC15

Obs	TLE
1	1 3908U 68091BL 15334.63610050 +.00000208 +00000-0 +48160-3 0 9993
	2 3908 063.3854 350.0503 0290154 358.7824 095.5330 13.32355900267949
2	1 3908U 68091BL 15337.41649815 +.00000213 +00000-0 +48976-3 0 9994
	2 3908 063.3853 343.0537 0290509 358.7976 111.6659 13.32357523268318
3	1 3908U 68091BL 15339.45152767 +.00000236 +00000-0 +52756-3 0 9991
	2 3908 063.3852 337.9325 0290707 358.8137 152.6594 13.32358856268586
4	1 3908U 68091BL 15341.00240814 +.00000266 +00000-0 +57610-3 0 9993
	2 3908 063.3851 334.0298 0290886 358.8254 031.4461 13.32360095268798
5	1 3908U 68091BL 15341.48041751 +.00000257 +00000-0 +56157-3 0 9999
	2 3908 063.3851 332.8269 0290953 358.8294 164.2147 13.32360343268850
6	1 03908U 68091BL 15337.18283404 .00000204 00000-0 47546-3 0 9998
	2 03908 63.3852 343.6416 0290445 358.7962 70.8997 13.32357380268685
7	1 03908U 68091BL 15339.21029287 .00000214 00000-0 49147-3 0 9991
	2 03908 63.3852 338.5396 0290666 358.8112 75.5799 13.32358602268958
8	1 03908U 68091BL 15341.23931684 .00000265 00000-0 57393-3 0 9997
	2 03908 63.3851 333.4336 0290905 358.8264 87.7783 13.32360251269221

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 59. Ephemeris Data Derived From TLEs for #03908

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	15 : 15 : 59.083	13.3236	0.0290154	63.3854	358.7824	350.0503	95.533
2	3-Dec	4 : 23 : 16.861	13.3236	290445	63.3852	358.7962	343.6416	70.8997
3	3-Dec	9 : 59 : 45.440	13.3236	290509	63.3853	358.7976	343.0537	111.6659
4	5-Dec	5 : 2 : 49.304	13.3236	290666	63.3852	358.8112	338.5396	75.5799
5	5-Dec	10 : 50 : 11.991	13.3236	290707	63.3852	358.8137	337.9325	152.6594
6	7-Dec	0 : 3 : 28.063	13.3236	290886	63.3851	358.8254	334.0298	31.4461
7	7-Dec	5 : 44 : 36.975	13.3236	290905	63.3851	358.8264	333.4336	87.7783
8	7-Dec	11 : 31 : 48.073	13.3236	290953	63.3851	358.8294	332.8269	164.2147

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 60. Error of Propagated Ephemeris for #03908

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.383	440.000	61.12160
→3	0.412	513	66.72954
→4	0.736	757	109.78062
→5	0.702	1482	115.57025
→6	1.071	1822	152.79138
→7	1.457	974	158.47719
→8	1.138	2217	164.26361
Obs 2→3	0.031	43	5.60794
→4	0.374	335	48.65901
→5	0.376	699	54.44865
→6	0.800	1095	91.66978
→7	1.127	599	97.35559
→8	0.882	1395	103.14200
Obs 3→4	0.329	296	43.05107
→5	0.358	626	48.84071
→6	0.745	1027	86.06184
→7	1.032	563	91.74765
→8	0.834	1319	97.53406
Obs 4→5	0.052	74	5.78964
→6	0.472	514	43.01077
→7	0.689	299	48.69658
→8	0.544	737	54.48299
Obs 5→6	0.337	445	37.22113
→7	0.501	263	42.90694
→8	0.384	659	48.69336
Obs 6→7	0.037	34	5.68581
→8	0.075	155	11.47222
Obs 7→8	0.062	78	5.78642

Figure 39. Error of the Two-Body Propagator Over Time–#03908

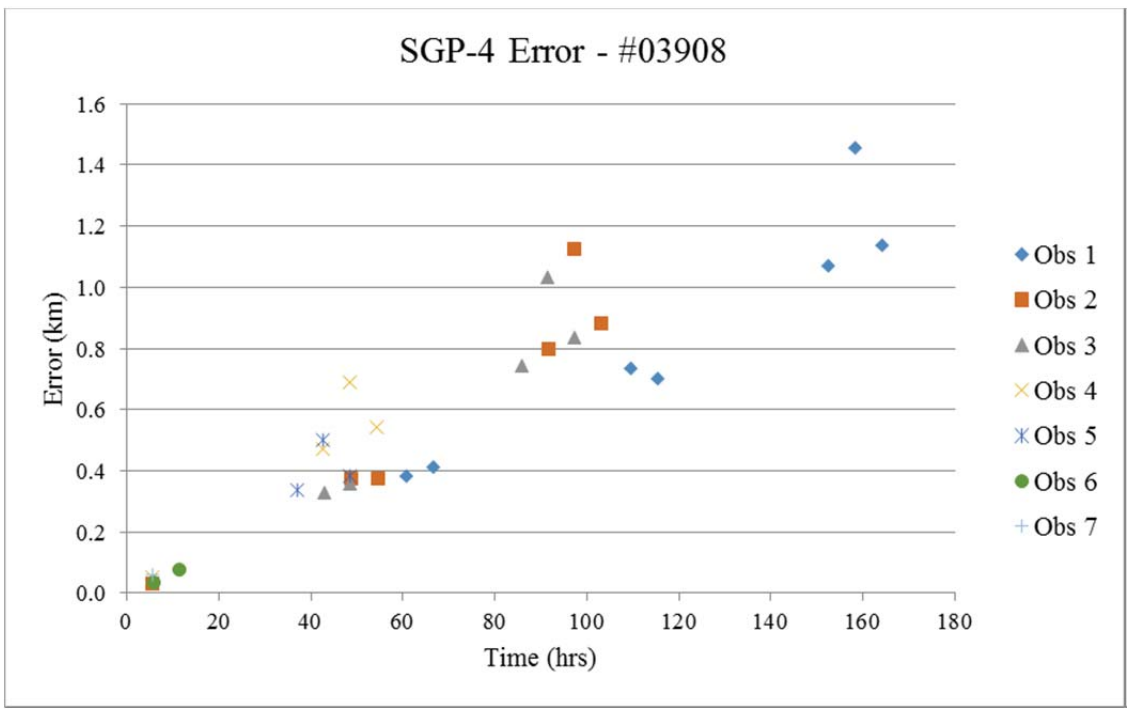

Figure 40. Error of the SGP-4 Propagator Over Time–#03908

U. CATALOG NUMBER 03923–COSMOS 249 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.06-0.07 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 61. Two-Line Element for #03923 30NOV–7DEC15

Obs	TLE
1	1 03923U 68091BR 15335.62448628 .00000742 00000-0 53470-3 0 9993
	2 03923 62.2299 194.6578 0642528 4.1782 356.4243 13.32605861221397
2	1 3923U 68091BR 15336.59997550 +.00000645 +00000-0 +47251-3 0 9995
	2 3923 062.2296 192.0870 0642625 004.4120 356.2191 13.32607156202262
3	1 3923U 68091BR 15337.57546369 +.00000606 +00000-0 +44786-3 0 9999
	2 3923 062.2294 189.5161 0642709 004.6483 356.0118 13.32608621202390
4	1 03923U 68091BR 15338.85110035 .00000557 00000-0 41686-3 0 9999
	2 03923 62.2292 186.1542 0642809 4.9598 355.7384 13.32610447221824
5	1 3923U 68091BR 15339.90162327 +.00000610 +00000-0 +45027-3 0 9990
	2 3923 062.2289 183.3856 0642911 005.2086 355.5202 13.32612372202709
6	1 3923U 68091BR 15340.87710782 +.00000661 +00000-0 +48223-3 0 9999
	2 3923 062.2288 180.8146 0642985 005.4439 355.3137 13.32614121202830
7	1 3923U 68091BR 15341.85259135 +.00000644 +00000-0 +47116-3 0 9999
	2 3923 062.2288 178.2437 0643068 005.6779 355.1083 13.32615453202967

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 62. Ephemeris Data Derived From TLEs for #03923

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	14 : 59 : 15.615	13.3261	0.0642528	62.2299	4.1782	194.6578	356.4243
2	2-Dec	14 : 23 : 57.883	13.3261	642625	62.2296	4.4120	192.0870	356.2191
3	3-Dec	13 : 48 : 40.063	13.3261	642709	62.2294	4.6483	189.5161	356.0118
4	4-Dec	20 : 25 : 35.070	13.3261	642809	62.2292	4.9598	186.1542	355.7384
5	5-Dec	21 : 38 : 20.251	13.3261	642911	62.2289	5.2086	183.3856	355.5202
6	6-Dec	21 : 3 : 2.116	13.3261	642985	62.2288	5.4439	180.8146	355.3137
7	7-Dec	20 : 27 : 43.893	13.3262	643068	62.2288	5.6779	178.2437	355.1083

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 63. Error of Propagated Ephemeris for #03923

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.103	304	23.41174
→3	0.174	607	46.82346
→4	0.306	1003	77.43874
→5	0.496	1329	102.65129
→6	0.822	1630	126.06292
→7	1.323	1928	149.47452
Obs 2→3	0.182	304	23.41172
→4	0.484	700	54.02700
→5	0.775	1026	79.23955
→6	0.971	1328	102.65118
→7	1.100	1627	126.06278
Obs 3→4	0.323	397	30.61528
→5	0.676	723	55.82783
→6	0.963	1025	79.23946
→7	1.223	1325	102.65106
Obs 4→5	0.363	326	25.21255
→6	0.705	629	48.62418
→7	1.076	930	72.03578
Obs 5→6	0.087	303	23.41163
→7	0.166	605	46.82323
Obs 6→7	0.190	302	23.41160

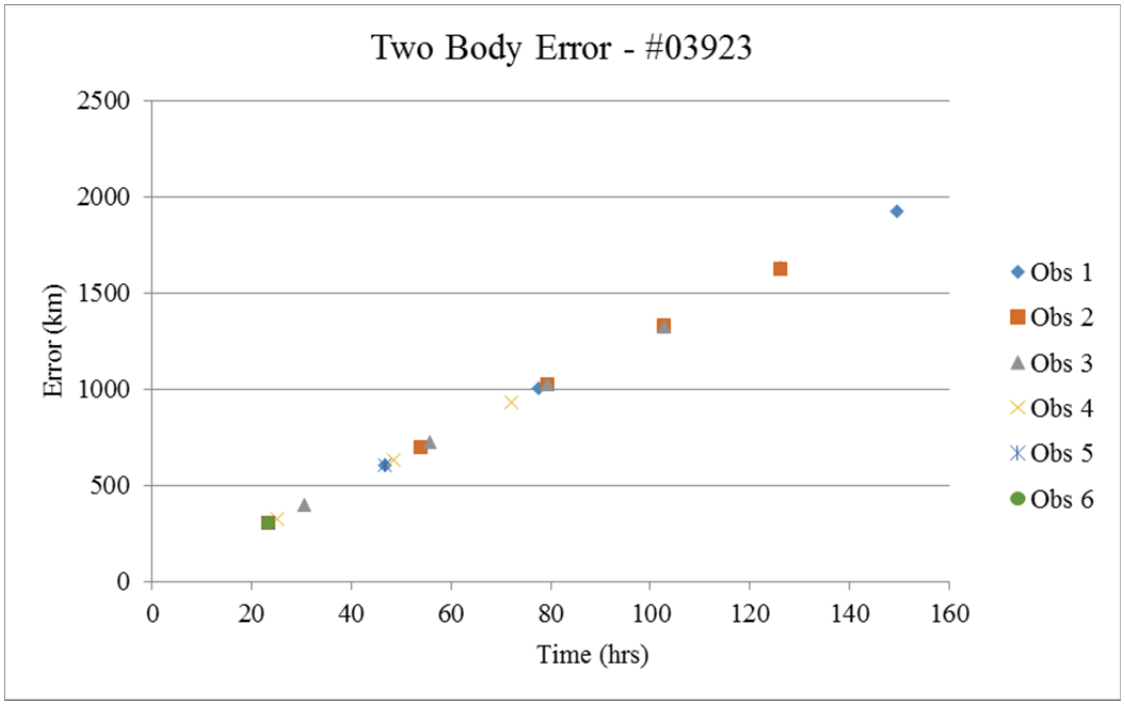

Figure 41. Error of the Two-Body Propagator Over Time–#03923

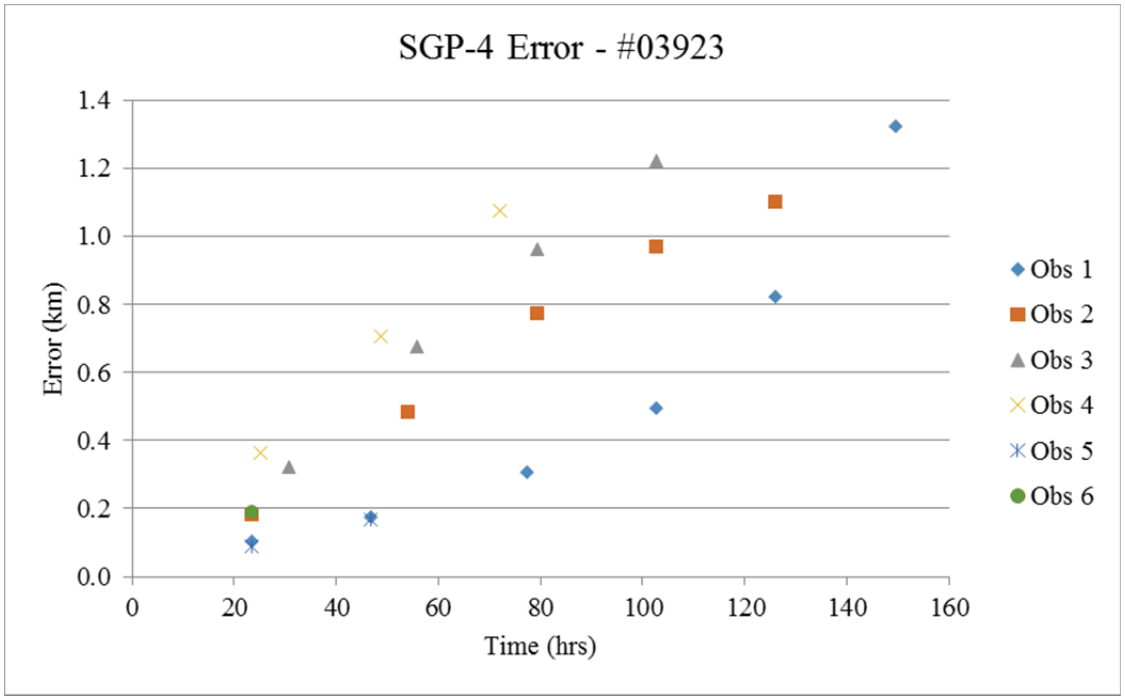

Figure 42. Error of the SGP-4 Propagator Over Time–#03923

V. CATALOG NUMBER 04071–SL-8 ROCKET BODY

This ephemeris data represents one of three samples for inclinations 70–80 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 64. Two-Line Element for #04071 30NOV–7DEC15

Obs	TLE
1	1 04071U 69070B 15334.97987633 .00000409 00000-0 86748-4 0 9992
	2 04071 74.0479 121.2198 0014313 246.4494 113.5170 14.62425039455372
2	1 04071U 69070B 15336.07440122 .00000411 00000-0 87183-4 0 9999
	2 04071 74.0480 119.1249 0014298 244.2995 115.6696 14.62425936455531
3	1 04071U 69070B 15337.78459543 .00000351 00000-0 75244-4 0 9993
	2 04071 74.0482 115.8516 0014257 240.8657 119.1084 14.62426926455782
4	1 04071U 69070B 15338.81071119 .00000329 00000-0 71017-4 0 9996
	2 04071 74.0484 113.8876 0014236 238.8339 121.1432 14.62427623455934
5	1 04071U 69070B 15339.83682635 .00000373 00000-0 79682-4 0 9995
	2 04071 74.0485 111.9237 0014218 236.8145 123.1659 14.62428672456083
6	1 04071U 69070B 15340.93134853 .00000402 00000-0 85294-4 0 9991
	2 04071 74.0487 109.8288 0014190 234.5613 125.4230 14.62429732456247

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 65. Ephemeris Data Derived From TLEs for #04071

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	23 : 31 : 1.315	14.6243	0.0014313	74.0479	246.4494	121.2198	113.5170
2	2-Dec	1 : 47 : 8.265	14.6243	14298	74.0480	244.2995	119.1249	115.6696
3	3-Dec	18 : 49 : 49.045	14.6243	14257	74.0482	240.8657	115.8516	119.1084
4	4-Dec	19 : 27 : 25.447	14.6243	14236	74.0484	238.8339	113.8876	121.1432
5	5-Dec	20 : 5 : 1.797	14.6243	14218	74.0485	236.8145	111.9237	123.1659
6	6-Dec	22 : 21 : 8.513	14.6243	14190	74.0487	234.5613	109.8288	125.4230

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 66. Error of Propagated Ephemeris for #04071

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.142	443	26.26860
→3	0.594	1133	67.31326
→4	0.897	1544	91.94004
→5	1.165	1953	116.56680
→6	1.468	2386	142.83533
Obs 2→3	0.414	691	41.04466
→4	0.697	1104	65.67144
→5	0.946	1515	90.29820
→6	1.228	1952	116.56674
Obs 3→4	0.091	414	24.62678
→5	0.188	828	49.25354
→6	0.338	1267	75.52207
Obs 4→5	0.155	414	24.62676
→6	0.387	855	50.89530
Obs 5→6	0.102	441	26.26853

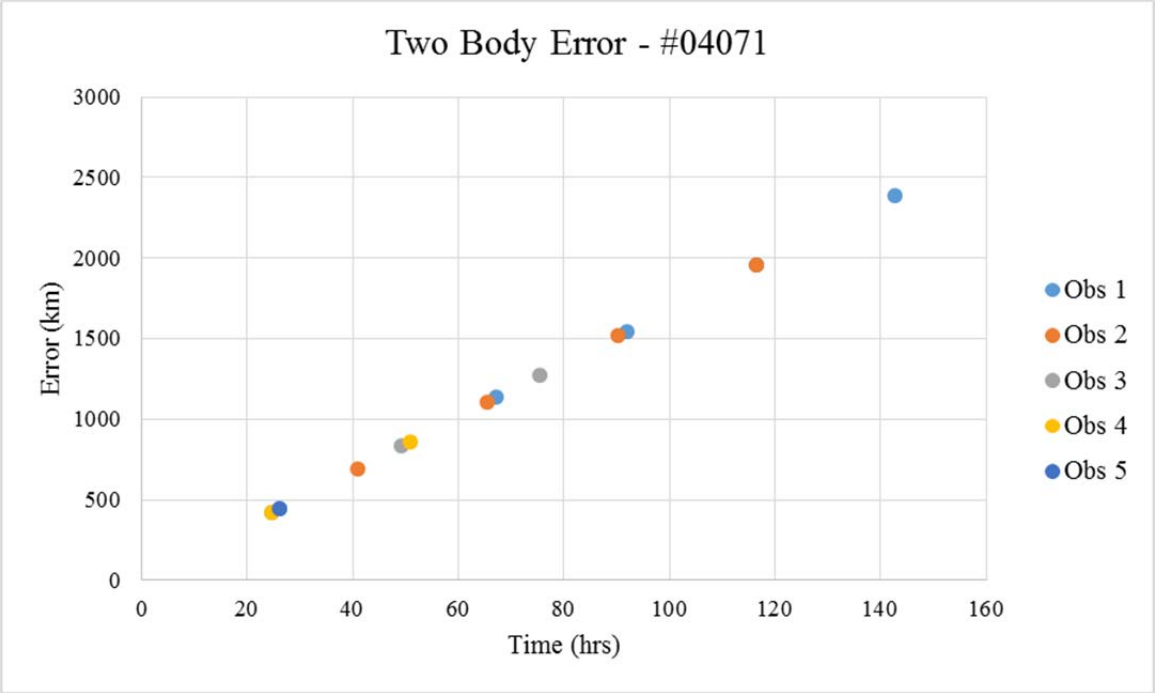

Figure 43. Error of the Two-Body Propagator Over Time–#04071

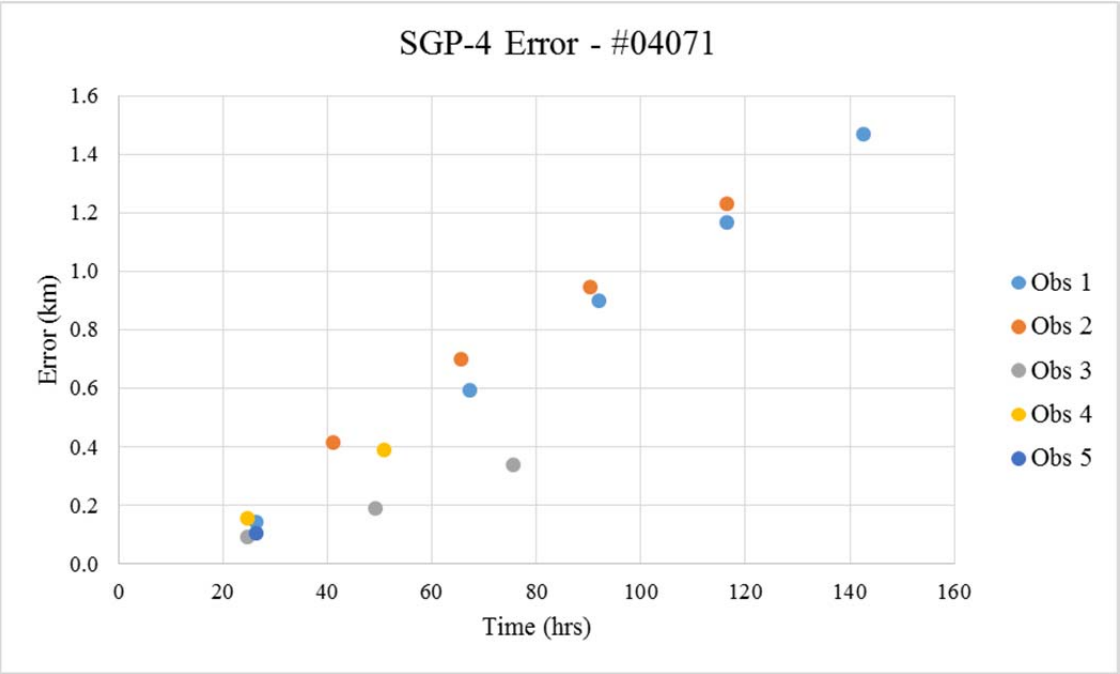

Figure 44. Error of the SGP-4 Propagator Over Time–#04071

W. CATALOG NUMBER 04369–COSMOS 332

This ephemeris data represents one of three samples for inclinations 70–80 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 67. Two-Line Element for #04369 30NOV–7DEC15

Obs	TLE
1	1 04369U 70028A 15335.04971331 .00000129 00000-0 39373-4 0 9995
	2 04369 74.0362 317.2612 0004742 57.8114 302.3506 14.51303013409644
2	1 04369U 70028A 15336.08368872 .00000134 00000-0 40501-4 0 9991
	2 04369 74.0363 315.3154 0004770 55.1415 305.0194 14.51303337409799
3	1 04369U 70028A 15337.11766394 .00000122 00000-0 37515-4 0 9995
	2 04369 74.0364 313.3697 0004796 52.4335 307.7261 14.51303550409947
4	1 04369U 70028A 15339.11668198 .00000106 00000-0 33601-4 0 9994
	2 04369 74.0366 309.6080 0004875 47.3050 312.8520 14.51304059410232
5	1 04369U 70028A 15340.35745128 .00000134 00000-0 40492-4 0 9998
	2 04369 74.0367 307.2731 0004919 44.1685 315.9868 14.51304605410414
6	1 04369U 70028A 15341.87394663 .00000131 00000-0 39831-4 0 9992
	2 04369 74.0368 304.4195 0004975 40.4174 319.7356 14.51305086410634

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 68. Ephemeris Data Derived From TLEs for #04369

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	1 : 11 : 35.230	14.5130	0.0004742	74.0362	57.8114	317.2612	302.3506
2	2-Dec	2 : 0 : 30.705	14.5130	4770	74.0363	55.1415	315.3154	305.0194
3	3-Dec	2 : 49 : 26.164	14.5130	4796	74.0364	52.4335	313.3697	307.7261
4	5-Dec	2 : 48 : 1.323	14.5130	4875	74.0366	47.3050	309.6080	312.8520
5	6-Dec	8 : 34 : 43.791	14.5130	4919	74.0367	44.1685	307.2731	315.9868
6	7-Dec	20 : 58 : 28.989	14.5131	4975	74.0368	40.4174	304.4195	319.7356

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 69. Error of Propagated Ephemeris for #04369

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.126	410	24.81541
→3	0.257	819	49.63082
→4	0.511	1605	97.60725
→5	0.652	2092	127.38571
→6	0.806	2679	163.78160
Obs 2→3	0.137	409	24.81541
→4	0.404	1199	72.79184
→5	0.553	1687	102.57030
→6	0.724	2278	138.96619
Obs 3→4	0.220	791	47.97643
→5	0.355	1280	77.75490
→6	0.511	1874	114.15078
Obs 4→5	0.175	491	29.77846
→6	0.393	1089	66.17435
Obs 5→6	0.158	600	36.39589

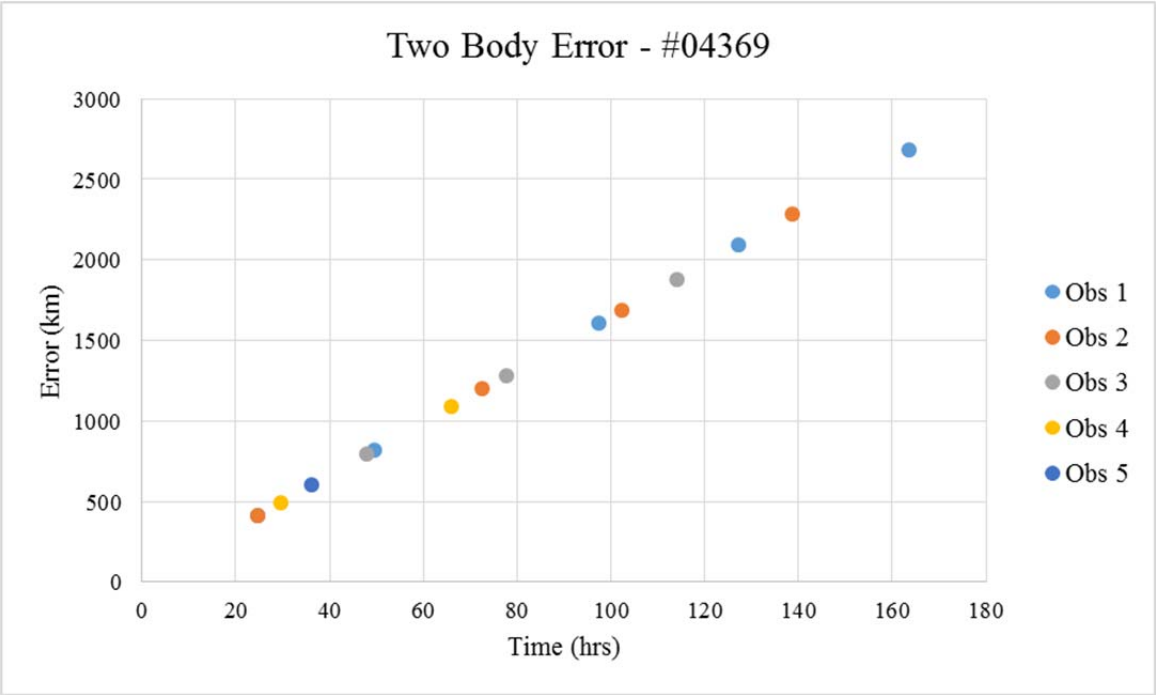

Figure 45. Error of the Two-Body Propagator Over Time–#04369

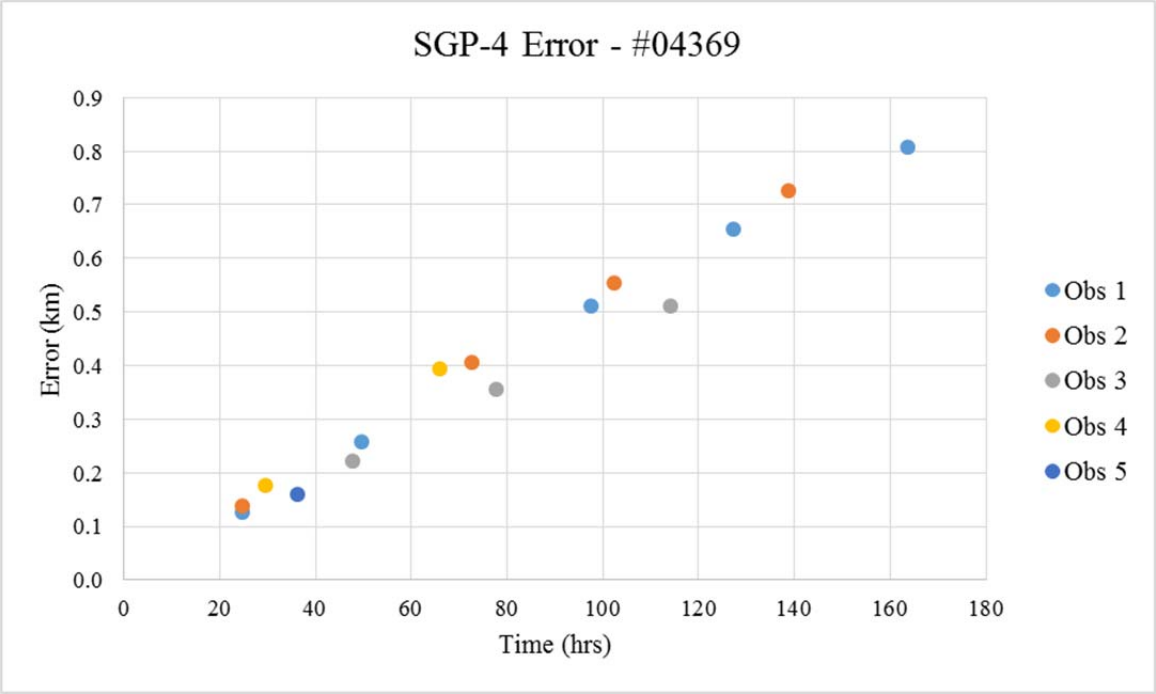

Figure 46. Error of the SGP-4 Propagator Over Time–#04369

X. CATALOG NUMBER 05197–COSMOS 397 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.07-0.08 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 70. Two-Line Element for #05197 30NOV–7DEC15

Obs	TLE
1	1 05197U 71015AT 15335.14934097 .00001678 00000-0 68622-3 0 9999 2 05197 65.5362 163.5391 0756181 142.8112 222.7860 13.32915447119216
2	1 5197U 71015AT 15336.95007382 +.00001535 +00000-0 +63144-3 0 9993 2 5197 065.5360 159.3060 0755984 142.0702 223.6157 13.32920835119224
3	1 5197U 71015AT 15337.10013439 +.00001538 +00000-0 +63237-3 0 9997 2 5197 065.5360 158.9531 0755974 142.0087 223.6846 13.32921394119245
4	1 5197U 71015AT 15338.90085869 +.00001397 +00000-0 +57830-3 0 9997 2 5197 065.5362 154.7202 0755832 141.2650 224.5165 13.32926498119486
5	1 5197U 71015AT 15339.87624661 +.00001775 +00000-0 +72497-3 0 9999 2 5197 065.5364 152.4274 0755755 140.8619 224.9670 13.32931923119615
6	1 5197U 71015AT 15340.85163181 +.00001975 +00000-0 +80279-3 0 9993 2 5197 065.5366 150.1347 0755691 140.4602 225.4157 13.32936525119743
7	1 05197U 71015AT 15341.52689796 .00002210 00000-0 89431-3 0 9995 2 05197 65.5366 148.5472 0755593 140.1814 225.7264 13.32938382120068
8	1 5197U 71015AT 15341.82701546 +.00002246 +00000-0 +90840-3 0 9991 2 5197 065.5365 147.8415 0755549 140.0581 225.8638 13.32939609119873

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 71. Ephemeris Data Derived From TLEs for #05197

Obs	Day	Time					MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	3	:	35	:	3.060	13.3292	0.0756181	65.5362	142.8112	163.5391	222.7860
2	2-Dec	22	:	48	:	6.378	13.3292	755984	65.5360	142.0702	159.3060	223.6157
3	3-Dec	2	:	24	:	11.611	13.3292	755974	65.5360	142.0087	158.9531	223.6846
4	4-Dec	21	:	37	:	14.191	13.3293	755832	65.5362	141.2650	154.7202	224.5165
5	5-Dec	21	:	1	:	47.707	13.3293	755755	65.5364	140.8619	152.4274	224.9670
6	6-Dec	20	:	26	:	20.988	13.3294	755691	65.5366	140.4602	150.1347	225.4157
7	7-Dec	12	:	38	:	43.984	13.3294	755593	65.5366	140.1814	148.5472	225.7264
8	7-Dec	19	:	50	:	54.136	13.3294	755549	65.5365	140.0581	147.8415	225.8638

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 72. Error of Propagated Ephemeris for #05197

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.540	637	43.21759
→3	0.537	690	46.81904
→4	1.658	1322	90.03643
→5	1.865	1664	113.44574
→6	1.962	2001	136.85498
→7	2.665	2236	153.06137
→8	2.758	2341	160.26419
Obs 2→3	0.144	53	3.60145
→4	0.171	687	46.81884
→5	0.594	1029	70.22815
→6	1.341	1368	93.63739
→7	1.328	1604	109.84378
→8	1.561	1709	117.04660
Obs 3→4	0.211	634	43.21738
→5	0.43	976	66.62669
→6	1.13	1315	90.03594
→7	1.095	1551	106.24233
→8	1.315	1656	113.44515
Obs 4→5	0.922	342	23.40931
→6	2.167	683	46.81855
→7	2.542	919	63.02494
→8	2.973	1024	70.22776
Obs 5→6	0.066	341	23.40924
→7	0.712	577	39.61563
→8	0.808	682	46.81845
Obs 6→7	1.008	236	16.20639
→8	1.269	341	23.40921
Obs 7→8	0.15	105	7.20282

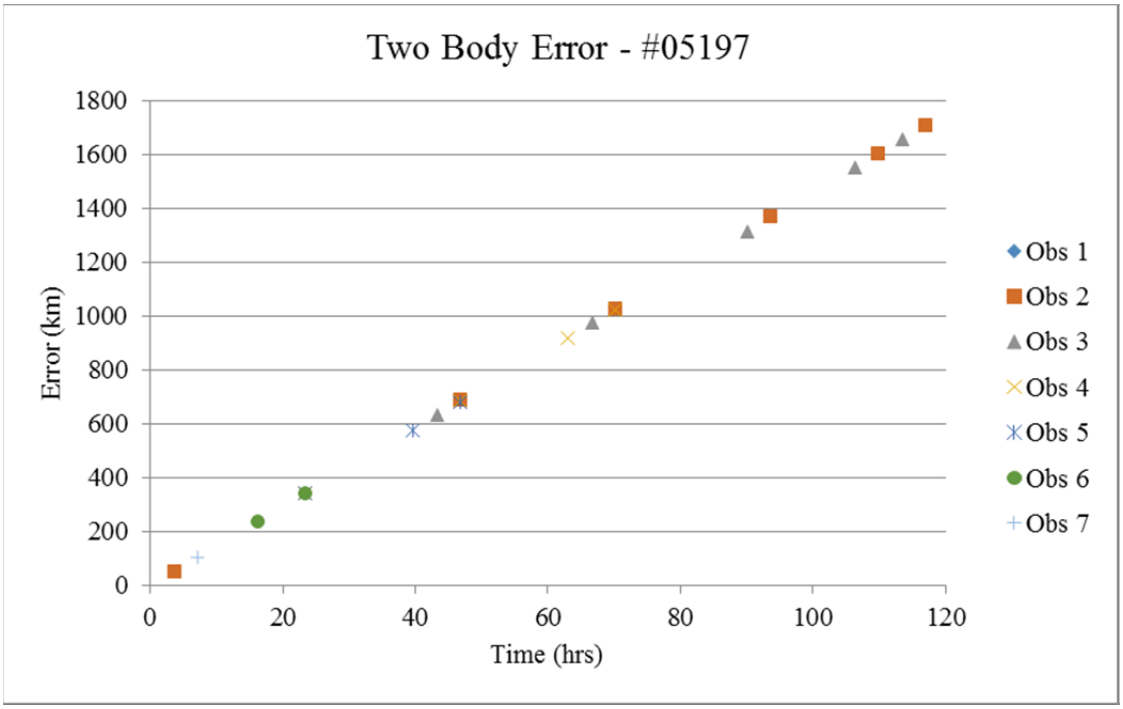

Figure 47. Error of the Two-Body Propagator Over Time–#05197

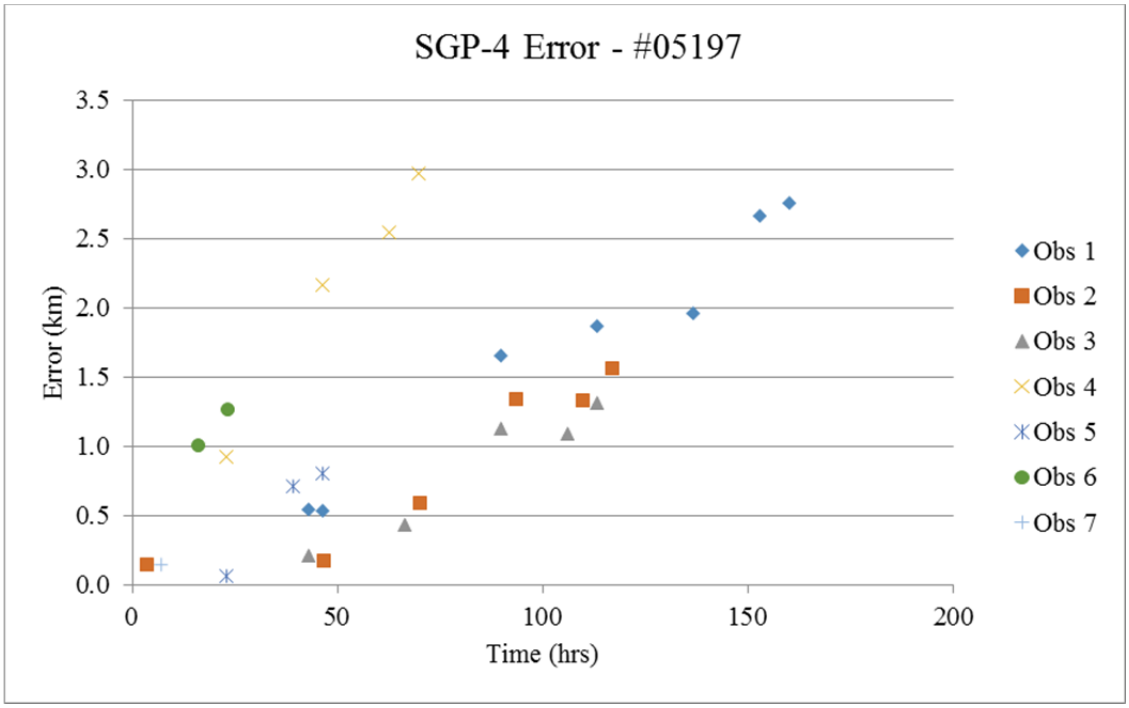

Figure 48. Error of the SGP-4 Propagator Over Time–#05197

Y. CATALOG NUMBER 05397–OV1-21

This ephemeris data represents one of three samples for semi-major axes 7200–7300 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 73. Two-Line Element for #05397 30NOV–7DEC15

Obs	TLE
1	1 05397U 71067B 15335.77012160 .00000082 00000-0 31326-4 0 9995
	2 05397 87.6304 24.0527 0080618 306.6625 52.7171 14.17380579289158
2	1 05397U 71067B 15337.18205559 .00000072 00000-0 26440-4 0 9998
	2 05397 87.6302 23.6748 0080530 302.0201 57.3180 14.17380736289357
3	1 05397U 71067B 15339.22936139 .00000072 00000-0 26495-4 0 9990
	2 05397 87.6300 23.1267 0080444 295.2827 64.0041 14.17380925289640
4	1 05397U 71067B 15340.50010391 .00000093 00000-0 36587-4 0 9992
	2 05397 87.6299 22.7865 0080393 291.1048 68.1559 14.17381133289820
5	1 05397U 71067B 15341.62965338 .00000103 00000-0 41752-4 0 9998
	2 05397 87.6298 22.4840 0080352 287.3956 71.8457 14.17381331289984

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 74. Ephemeris Data Derived From TLEs for #05397

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	18 : 28 : 58.506	14.1738	0.0080618	87.6304	306.6625	24.0527	52.7171
2	3-Dec	4 : 22 : 9.603	14.1738	80530	87.6302	302.0201	23.6748	57.3180
3	5-Dec	5 : 30 : 16.824	14.1738	80444	87.6300	295.2827	23.1267	64.0041
4	6-Dec	12 : 0 : 8.978	14.1738	80393	87.6299	291.1048	22.7865	68.1559
5	7-Dec	15 : 6 : 42.052	14.1738	80352	87.6298	287.3956	22.4840	71.8457

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 75. Error of Propagated Ephemeris for #05397

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.132	572	33.88642
→3	0.335	1399	83.02175
→4	0.499	1911	113.51958
→5	0.623	2365	140.62876
Obs 2→3	0.186	829	49.13534
→4	0.313	1343	79.63316
→5	0.410	1798	106.74235
Obs 3→4	0.114	515	30.49782
→5	0.206	972	57.60701
Obs 4→5	0.100	478	27.10919

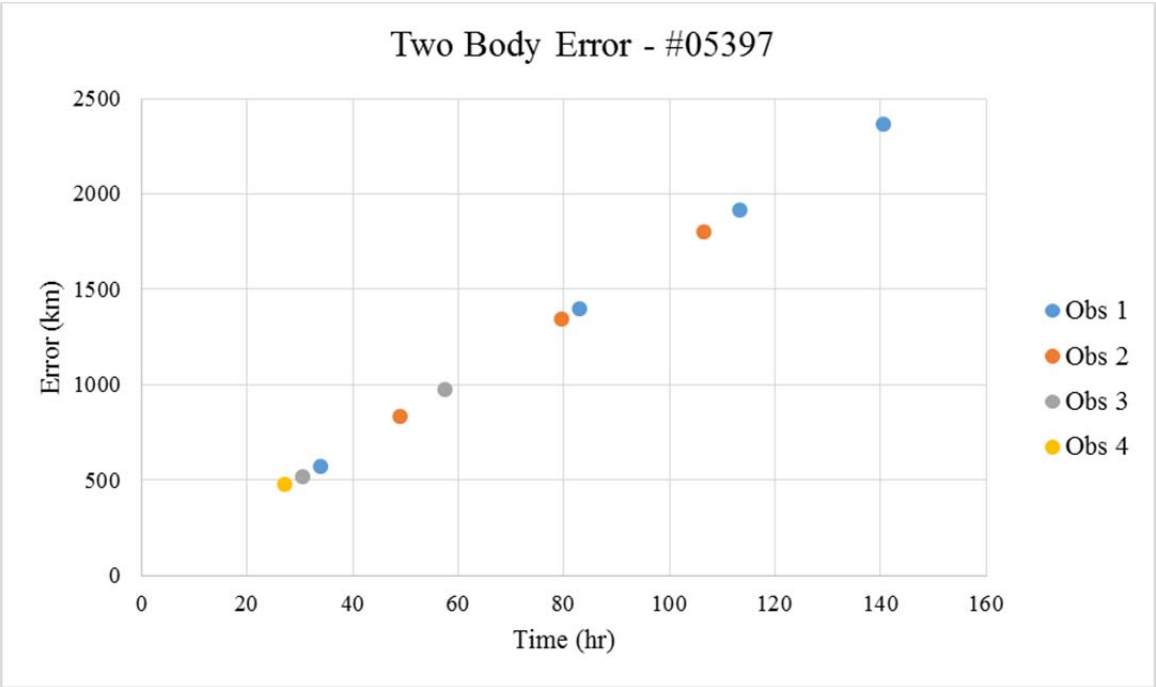

Figure 49. Error of the Two-Body Propagator Over Time–#05397

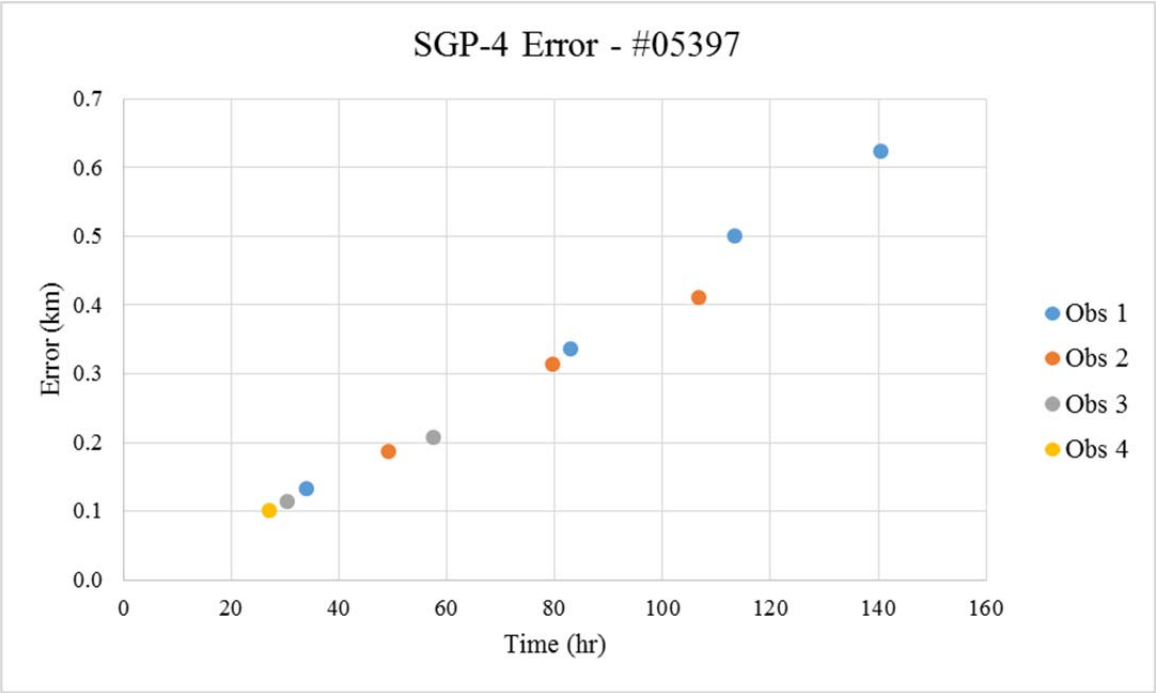

Figure 50. Error of the SGP-4 Propagator Over Time–#05397

Z. CATALOG NUMBER 05763–COSMOS 397 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.03-0.04 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 76. Two-Line Element for #05763 30NOV–7DEC15

Obs	TLE
1	1 05763U 71015CF 15334.51416466 .00000734 00000-0 11140-2 0 9997
	2 05763 66.9013 158.9578 0386060 249.7143 106.2023 13.31005997139177
2	1 5763U 71015CF 15336.91869331 +.00000697 +00000-0 +10629-2 0 9995
	2 5763 066.9014 153.6657 0386001 248.1748 107.7827 13.31009353139298
3	1 5763U 71015CF 15337.89553144 +.00000655 +00000-0 +10048-2 0 9994
	2 5763 066.9014 151.5157 0386001 247.5515 108.4232 13.31010534139421
4	1 05763U 71015CF 15339.84920472 .00000709 00000-0 10803-2 0 9992
	2 05763 66.9016 147.2161 0386015 246.3075 109.7027 13.31013752139884
5	1 5763U 71015CF 15340.52547510 +.00000737 +00000-0 +11189-2 0 9996
	2 5763 066.9017 145.7277 0386044 245.8770 110.1458 13.31014980139770
6	1 5763U 71015CF 15341.87801451 +.00000797 +00000-0 +12017-2 0 9999
	2 5763 066.9017 142.7506 0386081 245.0178 111.0310 13.31017336139952

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 77. Ephemeris Data Derived From TLEs for #05763

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	12 : 20 : 23.827	13.3101	0.0386060	66.9013	249.7143	158.9578	106.2023
2	2-Dec	22 : 2 : 55.102	13.3101	386001	66.9014	248.1748	153.6657	107.7827
3	3-Dec	21 : 29 : 33.916	13.3101	386001	66.9014	247.5515	151.5157	108.4232
4	5-Dec	20 : 22 : 51.288	13.3101	386015	66.9016	246.3075	147.2161	109.7027
5	6-Dec	12 : 36 : 41.049	13.3101	386044	66.9017	245.8770	145.7277	110.1458
6	7-Dec	21 : 4 : 20.454	13.3102	386081	66.9017	245.0178	142.7506	111.0310

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 78. Error of Propagated Ephemeris for #05763

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.578	808	57.70869
→3	0.904	1136	81.15280
→4	1.645	1789	128.04096
→5	1.785	2014	144.27145
→6	2.183	2464	176.73240
Obs 2→3	0.133	328	23.44412
→4	0.365	982	70.33227
→5	0.380	1209	86.56276
→6	0.537	1661	119.02371
Obs 3→4	0.284	655	46.88816
→5	0.538	881	63.11865
→6	1.069	1334	95.57959
Obs 4→5	0.140	226	16.23049
→6	0.375	680	48.69143
Obs 5→6	0.180	453	32.46095

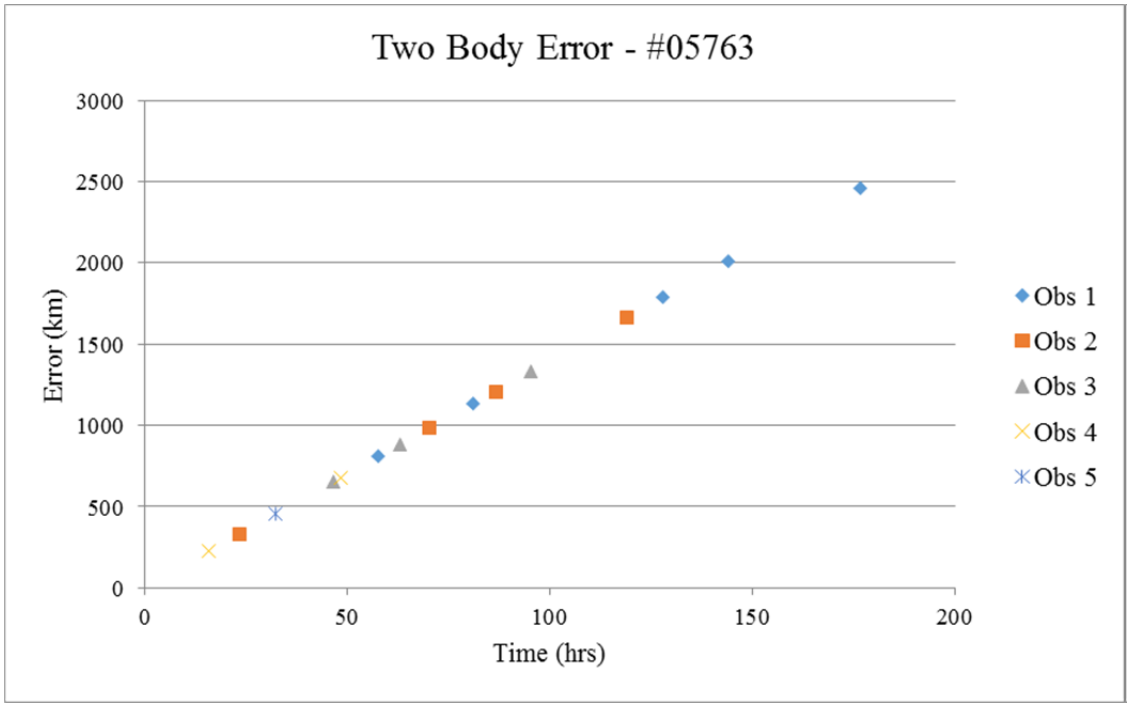

Figure 51. Error of the Two-Body Propagator Over Time–#05763

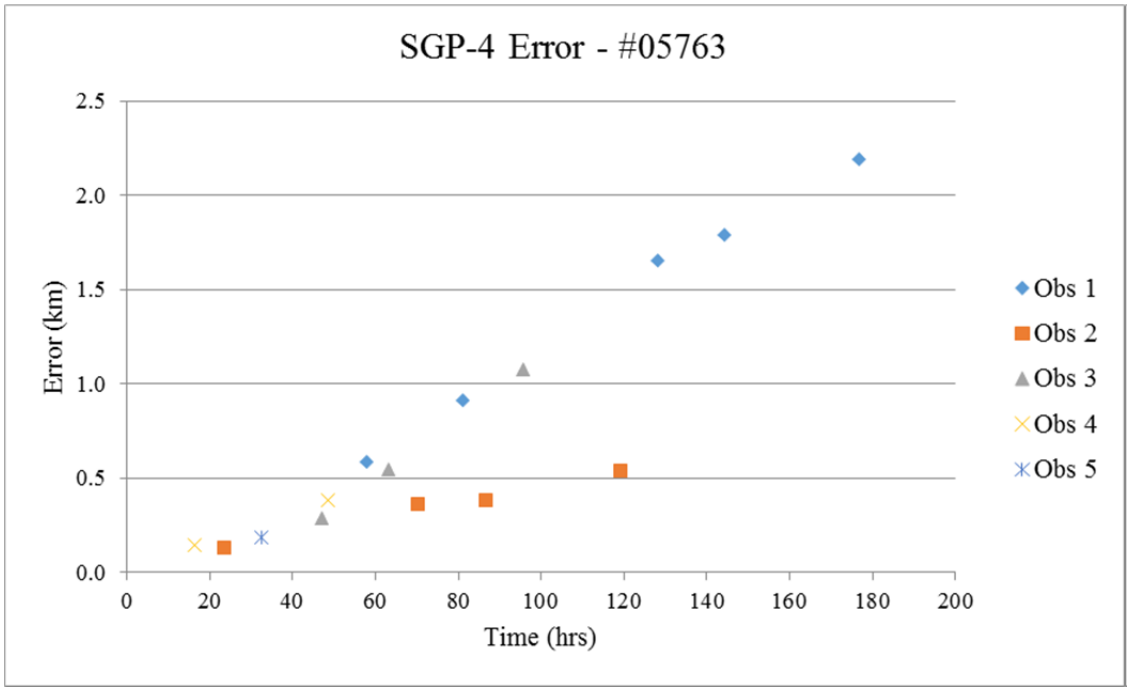

Figure 52. Error of the SGP-4 Propagator Over Time–#05763

AA. CATALOG NUMBER 06153–OAO 3

This ephemeris data represents one of three samples for inclinations 30–40 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 79. Two-Line Element for #06153 30NOV–7DEC15

Obs	TLE
1	1 06153U 72065A 15335.50373213 .00000172 00000-0 41578-4 0 9995 2 06153 35.0085 10.7699 0006595 158.2738 314.6742 14.57720095298588
2	1 6153U 72065A 15335.57613863 +.00000170 +00000-0 +41091-4 0 9998 2 6153 035.0085 010.3589 0006603 158.8829 334.6298 14.57720115298322
3	1 06153U 72065A 15336.54001668 .00000157 00000-0 38235-4 0 9991 2 06153 35.0085 4.8875 0006692 166.9560 352.6490 14.57720411298736
4	1 6153U 72065A 15337.35515509 +.00000149 +00000-0 +36651-4 0 9996 2 6153 035.0085 000.2604 0006773 173.7394 310.1909 14.57720657298586
5	1 06153U 72065A 15339.19724772 .00000123 00000-0 30869-4 0 9991 2 06153 35.0084 349.8038 0006940 188.7276 257.1483 14.57721088299126
6	1 6153U 72065A 15339.41290733 +.00000143 +00000-0 +35373-4 0 9998 2 6153 035.0084 348.5797 0006951 190.4388 308.9334 14.57721278298883
7	1 06153U 72065A 15340.44311499 .00000152 00000-0 37322-4 0 9992 2 06153 35.0084 342.7317 0007039 198.6353 315.4584 14.57721646299304
8	1 6153U 72065A 15340.98043378 +.00000166 +00000-0 +40152-4 0 9999 2 6153 035.0084 339.6816 0007086 202.9252 255.2909 14.57721883299116
9	1 6153U 72065A 15341.40060721 +.00000154 +00000-0 +37717-4 0 9998 2 6153 035.0084 337.2965 0007117 206.2090 300.4187 14.57721965299175

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 80. Ephemeris Data Derived From TLEs for #06153

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	12 : 5 : 22.456	14.5772	0.0006595	35.0085	158.2738	10.7699	314.6742
2	1-Dec	13 : 49 : 38.378	14.5772	6603	35.0085	158.8829	10.3589	334.6298
3	2-Dec	12 : 57 : 37.441	14.5772	6692	35.0085	166.9560	4.8875	352.6490
4	3-Dec	8 : 31 : 25.400	14.5772	6773	35.0085	173.7394	0.2604	310.1909
5	5-Dec	4 : 44 : 2.203	14.5772	6940	35.0084	188.7276	349.8038	257.1483
6	5-Dec	9 : 54 : 35.193	14.5772	6951	35.0084	190.4388	348.5797	308.9334
7	6-Dec	10 : 38 : 5.135	14.5772	7039	35.0084	198.6353	342.7317	315.4584
8	6-Dec	23 : 31 : 49.479	14.5772	7086	35.0084	202.9252	339.6816	255.2909
9	7-Dec	9 : 36 : 52.463	14.5772	7117	35.0084	206.2090	337.2965	300.4187

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 81. Error of Propagated Ephemeris for #06153

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.009	37	1.73776
→3	0.104	582	24.87083
→4	0.314	857	44.43415
→5	0.834	1655	88.64437
→6	0.833	1855	93.82020
→7	1.055	2493	118.54519
→8	0.797	3164	131.44084
→9	1.407	2727	141.52500
Obs 2→3	0.093	542	23.13307
→4	0.294	825	42.69640
→5	0.797	1621	86.90662
→6	0.794	1825	92.08245
→7	1.004	2462	116.80743
→8	0.752	3123	129.70308
→9	1.341	2700	139.78725
Obs 3→4	0.126	387	19.56332
→5	0.538	1177	63.77354
→6	0.517	1404	68.94938
→7	0.663	2029	93.67436
→8	0.502	2569	106.57001
→9	0.908	2322	116.65417
Obs 4→5	0.365	810	44.21022
→6	0.338	1028	49.38605
→7	0.457	1639	74.11104
→8	0.370	2094	87.00669
→9	0.649	1980	97.09085
Obs 5→6	0.013	113	5.17583
→7	0.067	688	29.90081
→8	0.111	1017	42.79647
→9	0.107	1134	52.88063
Obs 6→7	0.109	571	24.72498
→8	0.115	892	37.62063
→9	0.222	1029	47.70480
Obs 7→8	0.032	302	12.89565
→9	0.105	508	22.97981
Obs 8→9	0.083	225	10.08416

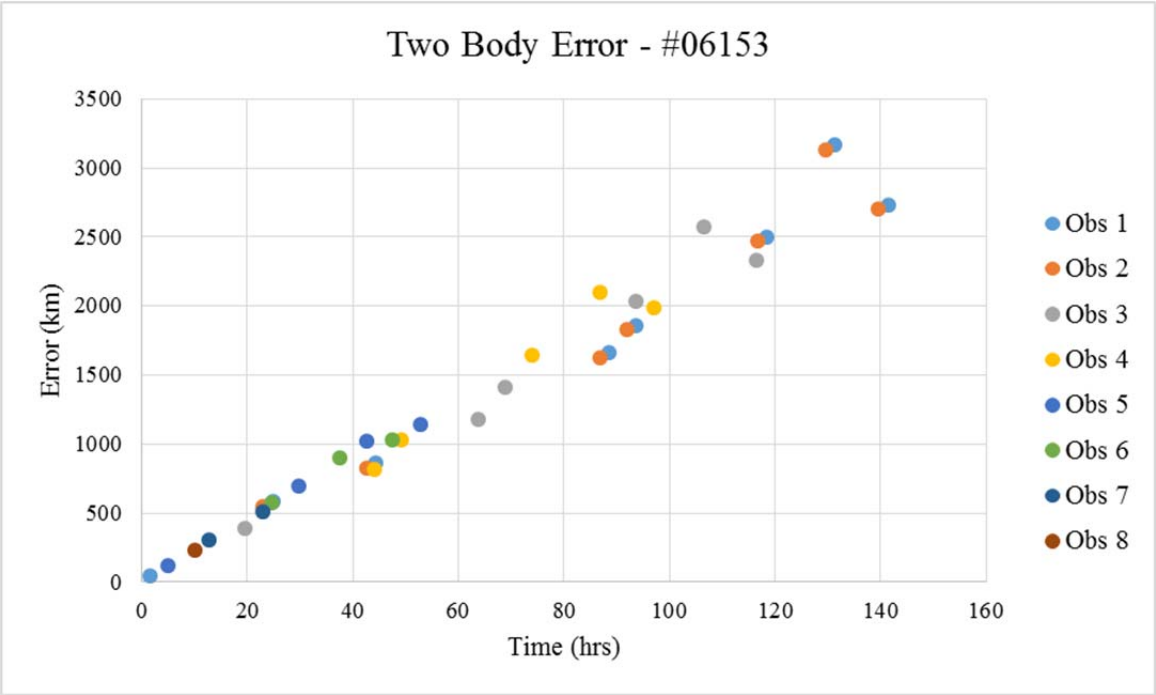

Figure 53. Error of the Two-Body Propagator Over Time–#06153

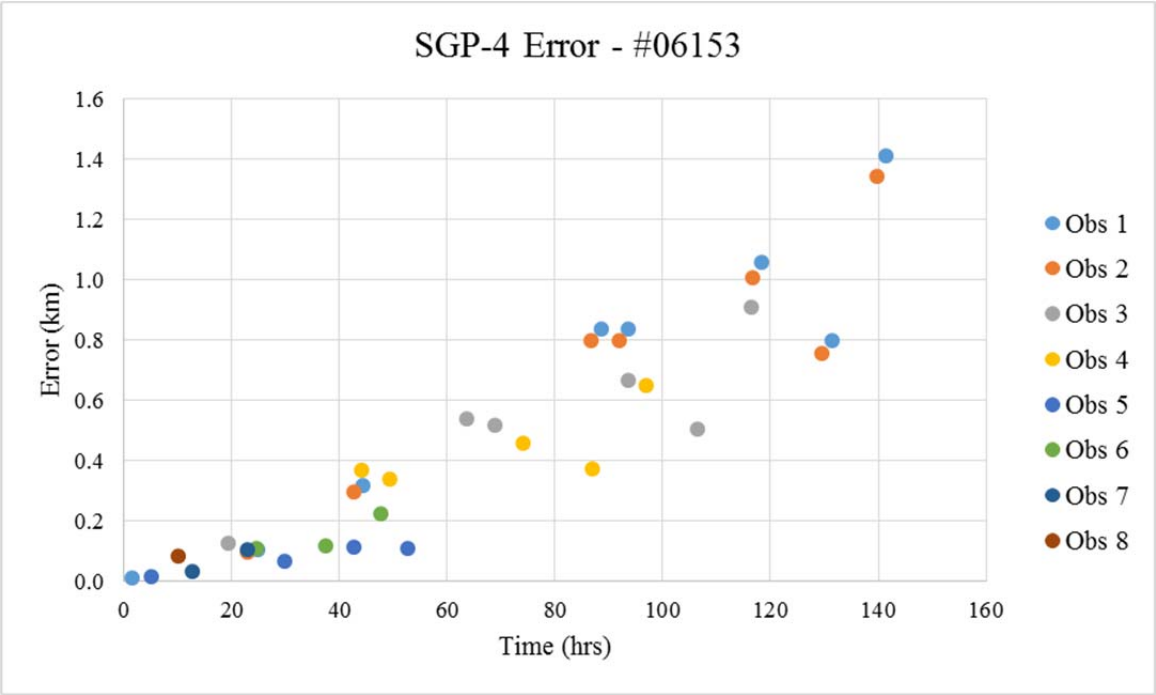

Figure 54. Error of the SGP-4 Propagator Over Time–#06153

BB. CATALOG NUMBER 09650–COSMOS 886 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.09-0.10 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 82. Two-Line Element for #09650 30NOV–7DEC15

Obs	TLE
1	1 9650U 76126G 15334.86017657 +.00002548 +00000-0 +61650-3 0 9998
	2 9650 065.8159 292.1659 0912453 338.7117 017.8121 13.21426317844909
2	1 9650U 76126G 15335.84404051 +.00002332 +00000-0 +56629-3 0 9996
	2 9650 065.8159 289.9115 0912504 338.2709 018.1818 13.21430019845035
3	1 09650U 76126G 15337.13062817 .00001894 00000-0 46424-3 0 9994
	2 09650 65.8157 286.9633 0912629 337.6935 18.6661 13.21433650844761
4	1 9650U 76126G 15337.88744010 +.00002108 +00000-0 +51370-3 0 9993
	2 9650 065.8156 285.2290 0912643 337.3537 018.9515 13.21438112845302
5	1 9650U 76126G 15338.94697568 +.00001852 +00000-0 +45423-3 0 9993
	2 9650 065.8158 282.8011 0912699 336.8792 019.3500 13.21441687845441
6	1 09650U 76126G 15339.17401874 .00001818 00000-0 44628-3 0 9990
	2 09650 65.8158 282.2809 0912719 336.7776 19.4354 13.21442386845034
7	1 9650U 76126G 15339.93082694 +.00002165 +00000-0 +52643-3 0 9991
	2 9650 065.8160 280.5467 0912746 336.4392 019.7198 13.21446766845573
8	1 9650U 76126G 15340.99035487 +.00002405 +00000-0 +58178-3 0 9993
	2 9650 065.8158 278.1184 0912835 335.9607 020.1219 13.21452213845711
9	1 09650U 76126G 15341.21739588 .00002475 00000-0 59780-3 0 9999
	2 09650 65.8158 277.5982 0912849 335.8589 20.2076 13.21453548845302
10	1 9650U 76126G 15341.89851857 +.00002291 +00000-0 +55504-3 0 9993
	2 9650 065.8160 276.0373 0912892 335.5525 020.4653 13.21456140845830

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 83. Ephemeris Data Derived From TLEs for #09650

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	20 : 38 : 39.256	13.2143	0.0912453	65.8159	338.7117	292.1659	17.8121
2	1-Dec	20 : 15 : 25.100	13.2143	912504	65.8159	338.2709	289.9115	18.1818
3	3-Dec	3 : 8 : 6.274	13.2143	912629	65.8157	337.6935	286.9633	18.6661
4	3-Dec	21 : 17 : 54.825	13.2144	912643	65.8156	337.3537	285.2290	18.9515
5	4-Dec	22 : 43 : 38.699	13.2144	912699	65.8158	336.8792	282.8011	19.3500
6	5-Dec	4 : 10 : 35.219	13.2144	912719	65.8158	336.7776	282.2809	19.4354
7	5-Dec	22 : 20 : 23.448	13.2145	912746	65.8160	336.4392	280.5467	19.7198
8	6-Dec	23 : 46 : 6.661	13.2145	912835	65.8158	335.9607	278.1184	20.1219
9	7-Dec	5 : 13 : 3.004	13.2145	912849	65.8158	335.8589	277.5982	20.2076
10	7-Dec	21 : 33 : 52.004	13.2146	912892	65.8160	335.5525	276.0373	20.4653

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 84. Error of Propagated Ephemeris for #09650

	Error (km)		
	SGP-4	Two Body	Time (hr)
Obs 1→2	1.161	299	23.61273
→3	4.162	688	54.49084
→4	5.097	913	72.65432
→5	8.215	1231	98.08318
→6	9.075	1299	103.53221
→7	11.631	1525	121.69561
→8	15.419	1839	147.12428
→9	16.132	1845	152.57326
→10	19.039	2102	168.92021
Obs 2→3	1.808	390	30.87810
→4	1.859	615	49.04159
→5	3.536	933	74.47044
→6	4.054	1001	79.91948
→7	5.391	1228	98.08287
→8	7.264	1543	123.51154
→9	7.534	1548	128.96053
→10	9.014	1806	145.30747
Obs 3→4	1.146	227	18.16349
→5	1.548	544	43.59234
→6	1.541	613	49.04137
→7	2.075	839	67.20477
→8	3.263	1155	92.63344
→9	3.709	1160	98.08243
→10	4.565	1420	114.42937

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 4→5	0.534	321	25.42885
→6	0.771	389	30.87789
→7	1.095	618	49.04128
→8	1.343	936	74.46995
→9	1.239	942	79.91894
→10	1.463	1205	96.26588
Obs 5→6	0.102	69	5.44903
→7	0.191	297	23.61243
→8	1.024	616	49.04110
→9	1.398	622	54.49008
→10	2.075	885	70.83703
Obs 6→7	0.347	228	18.16340
→8	1.344	547	43.59207
→9	1.759	553	49.04105
→10	2.564	816	65.38800
Obs 7→8	0.175	322	25.42867
→9	0.24	328	30.87765
→10	0.291	594	47.22460
Obs 8→9	0.075	12	5.44898
→10	0.362	274	21.79593
Obs 9→10	0.505	267	16.34694

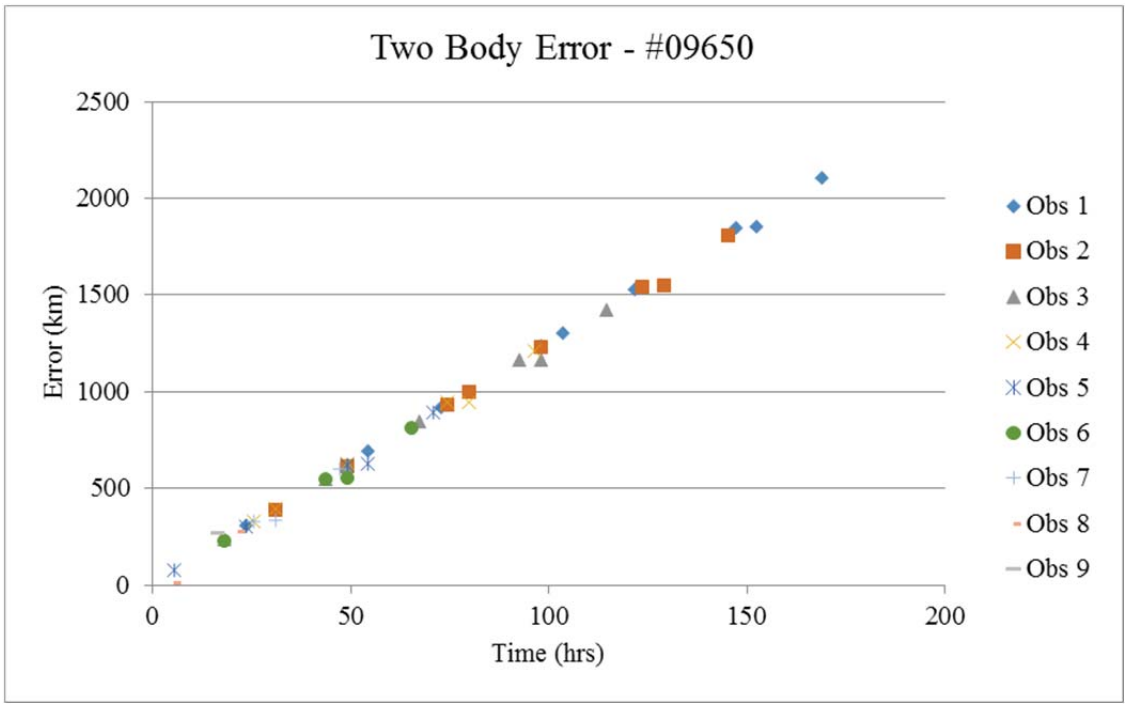

Figure 55. Error of the Two-Body Propagator Over Time–#09650

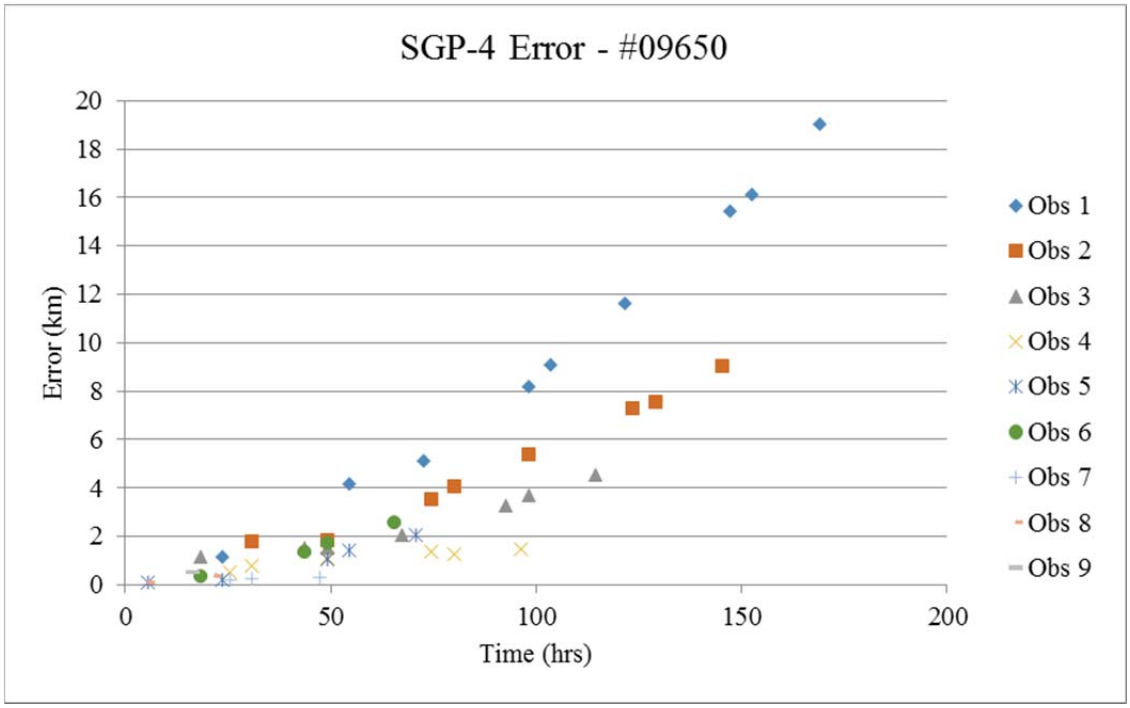

Figure 56. Error of the SGP-4 Propagator Over Time–#09650

CC. CATALOG NUMBER 09963–COSMOS 886 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.08-0.09 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 85. Two-Line Element for #09963 30NOV–7DEC15

Obs	TLE
1	1 9963U 76126BD 15334.70263403 +.00000747 +00000-0 +27877-3 0 9992
	2 9963 065.7981 071.8863 0833016 016.0866 346.4982 13.24465627842512
2	1 9963U 76126BD 15336.74135554 +.00000571 +00000-0 +22047-3 0 9992
	2 9963 065.7983 067.2003 0833163 015.1632 347.2817 13.24467414842784
3	1 9963U 76126BD 15337.72296061 +.00000545 +00000-0 +21169-3 0 9997
	2 9963 065.7983 064.9441 0833231 014.7196 347.6578 13.24468545842919
4	1 9963U 76126BD 15339.68616769 +.00000619 +00000-0 +23604-3 0 9993
	2 9963 065.7984 060.4315 0833354 013.8326 348.4096 13.24471476843172
5	1 9963U 76126BD 15340.96980070 +.00000709 +00000-0 +26580-3 0 9991
	2 9963 065.7984 057.4810 0833428 013.2526 348.9009 13.24473759843340
6	1 9963U 76126BD 15341.64937069 +.00000720 +00000-0 +26937-3 0 9996
	2 9963 065.7984 055.9189 0833475 012.9449 349.1614 13.24474698843432
7	1 09963U 76126BD 15335.75974954 .00000641 00000-0 24357-3 0 9991
	2 09963 65.7982 69.4565 0833091 15.6076 346.9047 13.24466460842171
8	1 09963U 76126BD 15339.23312044 .00000466 00000-0 18573-3 0 9992
	2 09963 65.7983 61.4729 0833334 14.0368 348.2366 13.24470034842635
9	1 09963U 76126BD 15341.49835509 .00000706 00000-0 26466-3 0 9996
	2 09963 65.7984 56.2661 0833462 13.0135 349.1033 13.24474449842934

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 86. Ephemeris Data Derived From TLEs for #09963

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	16 : 51 : 47.580	13.2447	0.0833016	65.7981	16.0866	71.8863	346.4982
2	1-Dec	18 : 14 : 2.360	13.2447	833091	65.7982	15.6076	69.4565	346.9047
3	2-Dec	17 : 47 : 33.119	13.2447	833163	65.7983	15.1632	67.2003	347.2817
4	3-Dec	17 : 21 : 3.797	13.2447	833231	65.7983	14.7196	64.9441	347.6578
5	5-Dec	5 : 35 : 41.606	13.2447	833334	65.7983	14.0368	61.4729	348.2366
6	5-Dec	16 : 28 : 4.888	13.2447	833354	65.7984	13.8326	60.4315	348.4096
7	6-Dec	23 : 16 : 30.780	13.2447	833428	65.7984	13.2526	57.4810	348.9009
8	7-Dec	11 : 57 : 37.880	13.2447	833462	65.7984	13.0135	56.2661	349.1033
9	7-Dec	15 : 35 : 5.628	13.2447	833475	65.7984	12.9449	55.9189	349.1614

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 87. Error of Propagated Ephemeris for #09963

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.827	324	25.37077
→3	1.629	624	48.92932
→4	2.647	923	72.48784
→5	4.651	1382	108.73167
→6	5.153	1518	119.60481
→7	7.020	1906	150.41200
→8	7.965	2065	163.09731
→9	8.301	2109	166.72168
Obs 2→3	0.273	300	23.55854
→4	0.659	600	47.11707
→5	1.478	1059	83.36090
→6	1.581	1196	94.23404
→7	2.183	1585	125.04123
→8	2.553	1744	137.72653
→9	2.720	1789	141.35091
Obs 3→4	0.126	300	23.55852
→5	0.391	760	59.80236
→6	0.337	897	70.67549
→7	0.389	1286	101.48268
→8	0.456	1446	114.16799
→9	0.516	1491	117.79236
Obs 4→5	0.143	460	36.24384
→6	0.199	598	47.11697
→7	0.469	988	77.92416
→8	0.524	1148	90.60947
→9	0.500	1193	94.23384
Obs 5→6	0.271	138	10.87313
→7	0.969	528	41.68033
→8	1.217	688	54.36563
→9	1.228	734	57.99001
Obs 6→7	0.116	390	30.80719
→8	0.238	551	43.49250
→9	0.344	596	47.11687
Obs 7→8	0.273	161	12.68531
→9	0.434	206	16.30968
Obs 8→9	0.150	46	3.62437

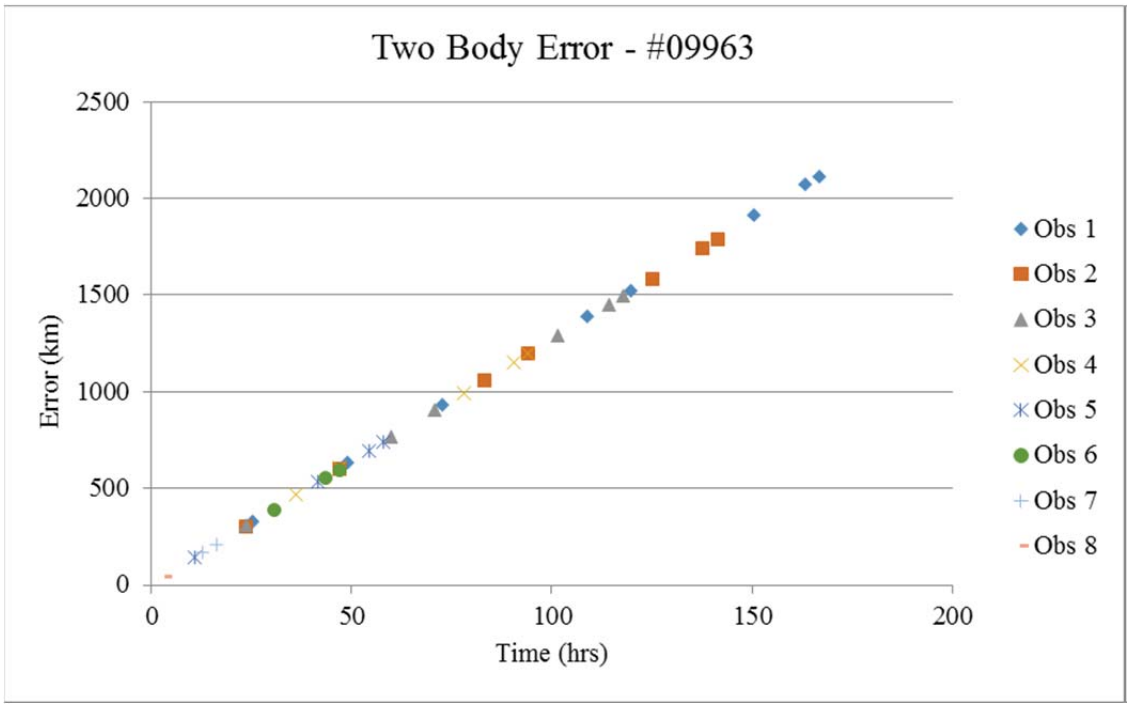

Figure 57. Error of the Two-Body Propagator Over Time–#09963

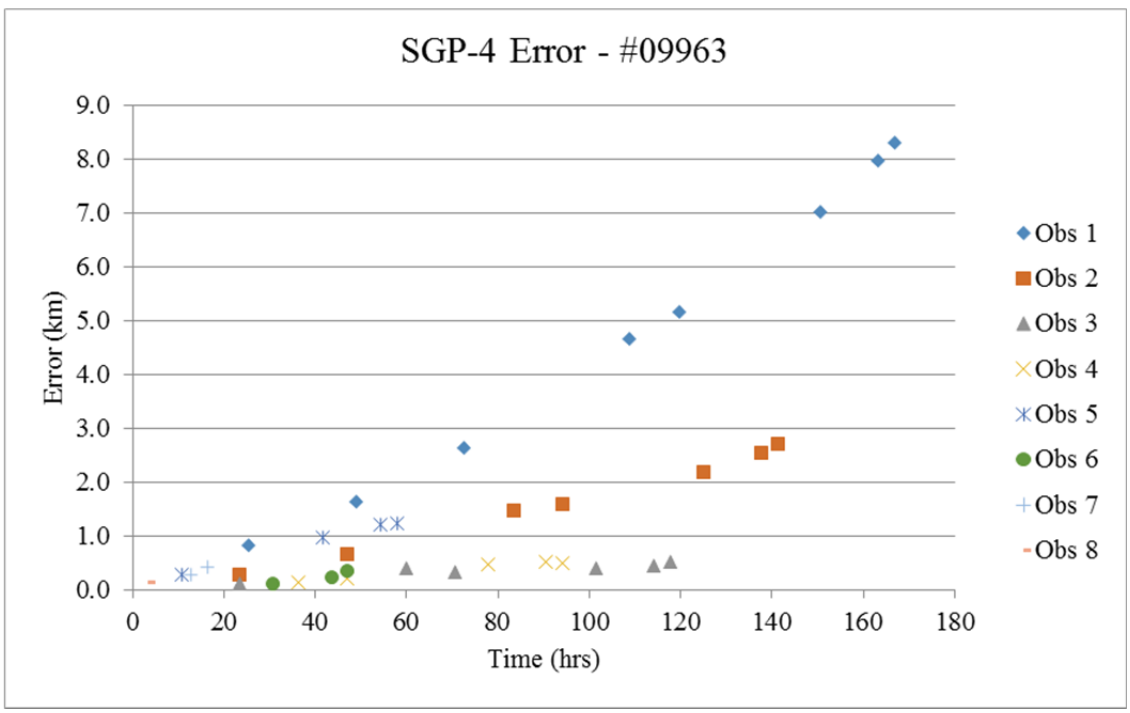

Figure 58. Error of the SGP-4 Propagator Over Time–#09963

DD. CATALOG NUMBER 10562–SCOUT D-1 ROCKET BODY

This ephemeris data represents one of three samples for eccentricities 0.00-0.01 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 88. Two-Line Element for #10562 30NOV–7DEC15

Obs	TLE
1	1 10562U 77121D 15334.93547730 +.00000064 +00000-0 +26215-3 0 9995
	2 10562 065.8679 154.8385 0085885 081.1945 067.3167 13.35585401847018
2	1 10562U 77121D 15335.96924979 +.00000069 +00000-0 +27146-3 0 9992
	2 10562 065.8679 152.4551 0085918 080.6586 357.8589 13.35585661847157
3	1 10562U 77121D 15336.41884544 .00000069 00000-0 27165-3 0 9997
	2 10562 65.8679 151.4186 0085922 80.4235 359.5886 13.35585783847440
4	1 10562U 77121D 15336.95988885 +.00000068 +00000-0 +26988-3 0 9990
	2 10562 065.8679 150.1713 0085929 080.1421 081.0130 13.35585925847282
5	1 10562U 77121D 15337.93141358 +.00000058 +00000-0 +25062-3 0 9996
	2 10562 065.8680 147.9315 0085940 079.6402 072.2584 13.35586126847415
6	1 10562U 77121D 15338.88853102 .00000071 00000-0 27603-3 0 9996
	2 10562 65.8681 145.7249 0085903 79.1408 354.2375 13.35586444847771
7	1 10562U 77121D 15339.86154028 +.00000087 +00000-0 +30569-3 0 9998
	2 10562 065.8682 143.4816 0085895 078.6376 352.6233 13.35586776847677
8	1 10562U 77121D 15340.92813527 .00000074 00000-0 28139-3 0 9999
	2 10562 65.8683 141.0225 0085899 78.0884 80.9832 13.35587022848041

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 89. Ephemeris Data Derived From TLEs for #10562

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22 : 27 : 5.239	13.3559	0.0085885	65.8679	81.1945	154.8385	67.3167
2	1-Dec	23 : 15 : 43.182	13.3559	85918	65.8679	80.6586	152.4551	357.8589
3	2-Dec	10 : 3 : 8.246	13.3559	85922	65.8679	80.4235	151.4186	359.5886
4	2-Dec	23 : 2 : 14.397	13.3559	85929	65.8679	80.1421	150.1713	81.0130
5	3-Dec	22 : 21 : 14.133	13.3559	85940	65.8680	79.6402	147.9315	72.2584
6	4-Dec	21 : 19 : 29.080	13.3559	85903	65.8681	79.1408	145.7249	354.2375
7	5-Dec	20 : 40 : 37.080	13.3559	85895	65.8682	78.6376	143.4816	352.6233
8	6-Dec	22 : 16 : 30.887	13.3559	85899	65.8683	78.0884	141.0225	80.9832

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 90. Error of Propagated Ephemeris for #10562

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.047	203	24.81054
→3	0.079	284	35.60084
→4	0.180	657	48.58588
→5	0.234	919	71.90247
→6	0.310	798	94.87329
→7	0.394	1015	118.22551
→8	0.520	1901	143.82379
Obs 2→3	0.041	86	10.79030
→4	0.083	322	23.77534
→5	0.150	602	47.09193
→6	0.283	591	70.06275
→7	0.361	805	93.41497
→8	0.423	1573	119.01325
Obs 3→4	0.046	175	12.98504
→5	0.114	463	36.30164
→6	0.248	500	59.27245
→7	0.328	713	82.62468
→8	0.389	1430	108.22296
Obs 4→5	0.072	297	23.31659
→6	0.200	391	46.28741
→7	0.287	602	69.63963
→8	0.346	1258	95.23791
Obs 5→6	0.171	195	22.97082
→7	0.303	401	46.32304
→8	0.281	950	71.92132
Obs 6→7	0.097	203	23.35222
→8	0.182	646	48.95050
Obs 7→8	0.099	337	25.59828

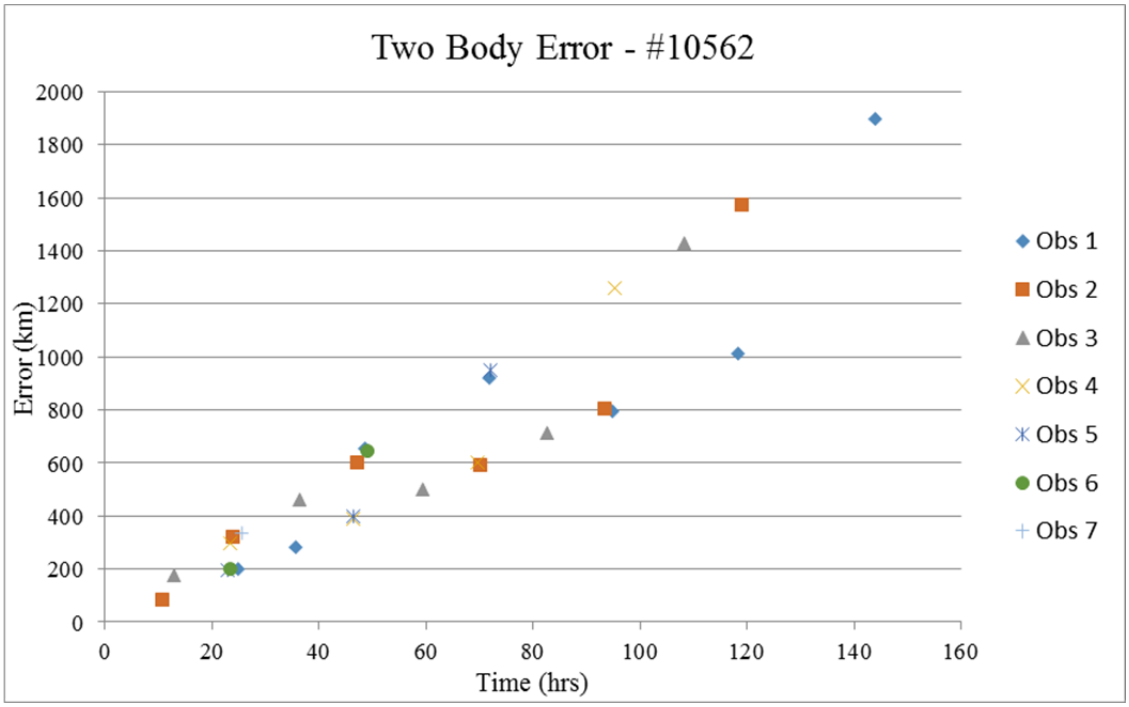

Figure 59. Error of the Two-Body Propagator Over Time–#10562

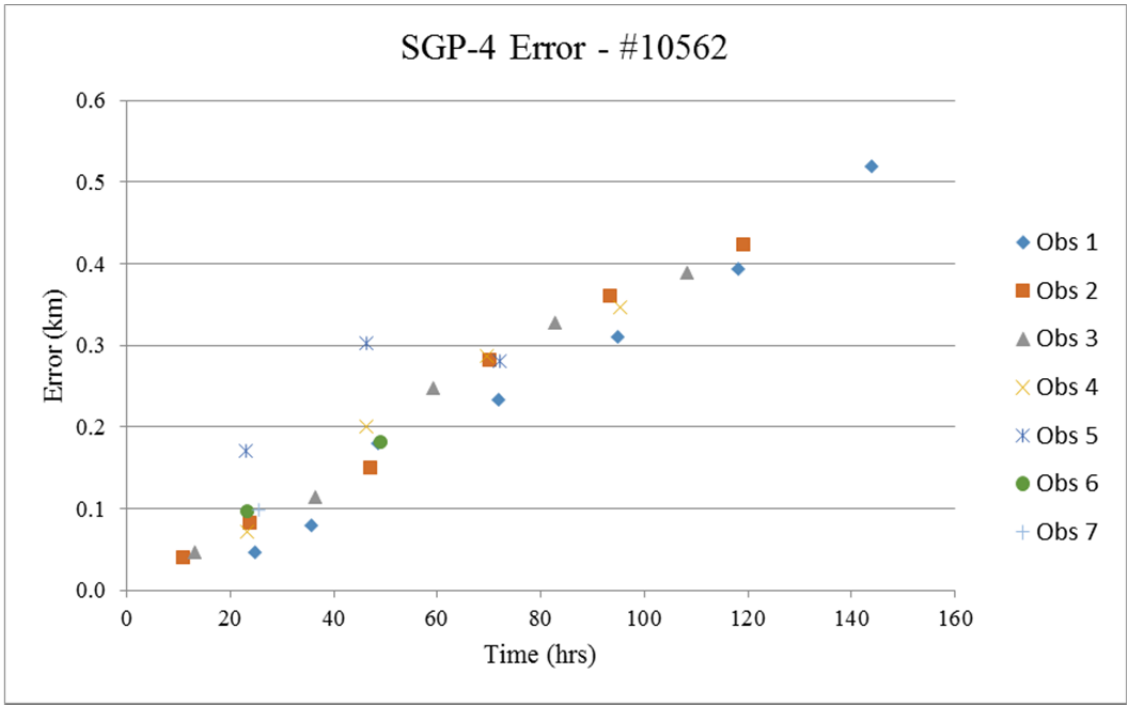

Figure 60. Error of the SGP-4 Propagator Over Time–#10562

EE. CATALOG NUMBER 10566–COSMOS 970 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.04-0.05 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 91. Two-Line Element for #10566 30NOV–7DEC15

Obs	TLE
1	1 10566U 77121H 15335.58746656 +.00000923 +00000-0 +15132-2 0 9998 2 10566 065.7877 350.0973 0415250 158.8685 203.0084 13.22258669819396
2	1 10566U 77121H 15337.17581554 .00000999 00000-0 16294-2 0 9992 2 10566 65.7876 346.4966 0415069 158.1581 203.7742 13.22262032819861
3	1 10566U 77121H 15337.40272159 +.00001051 +00000-0 +17079-2 0 9998 2 10566 065.7878 345.9821 0415137 158.0540 203.8869 13.22262977819631
4	1 10566U 77121H 15339.52050917 .00001190 00000-0 19210-2 0 9992 2 10566 65.7878 341.1812 0414816 157.1021 204.9120 13.22269372820175
5	1 10566U 77121H 15340.42812849 +.00001335 +00000-0 +21423-2 0 9993 2 10566 065.7880 339.1239 0414829 156.6974 205.3483 13.22273051820034

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 92. Ephemeris Data Derived From TLEs for #10566

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	14 : 5 : 57.111	13.2226	0.041525	65.7877	158.8685	350.0973	203.0084
2	3-Dec	4 : 13 : 10.463	13.2226	415069	65.7876	158.1581	346.4966	203.7742
3	3-Dec	9 : 39 : 55.145	13.2226	415137	65.7878	158.054	345.9821	203.8869
4	5-Dec	12 : 29 : 31.992	13.2227	414816	65.7878	157.1021	341.1812	204.912
5	6-Dec	10 : 16 : 30.302	13.2227	414829	65.788	156.6974	339.1239	205.3483

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 93. Error of Propagated Ephemeris for #10566

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.246	539	38.12038
→3	0.562	616	43.56612
→4	3.324	1330	94.39302
→5	5.612	1634	116.17589
Obs 2→3	0.386	77	5.44575
→4	2.763	792	56.27265
→5	4.794	1097	78.05551
Obs 3→4	1.852	715	50.82690
→5	3.582	1020	72.60977
Obs 4→5	1.003	305	21.78286

Figure 61. Error of the Two-Body Propagator Over Time–#10566

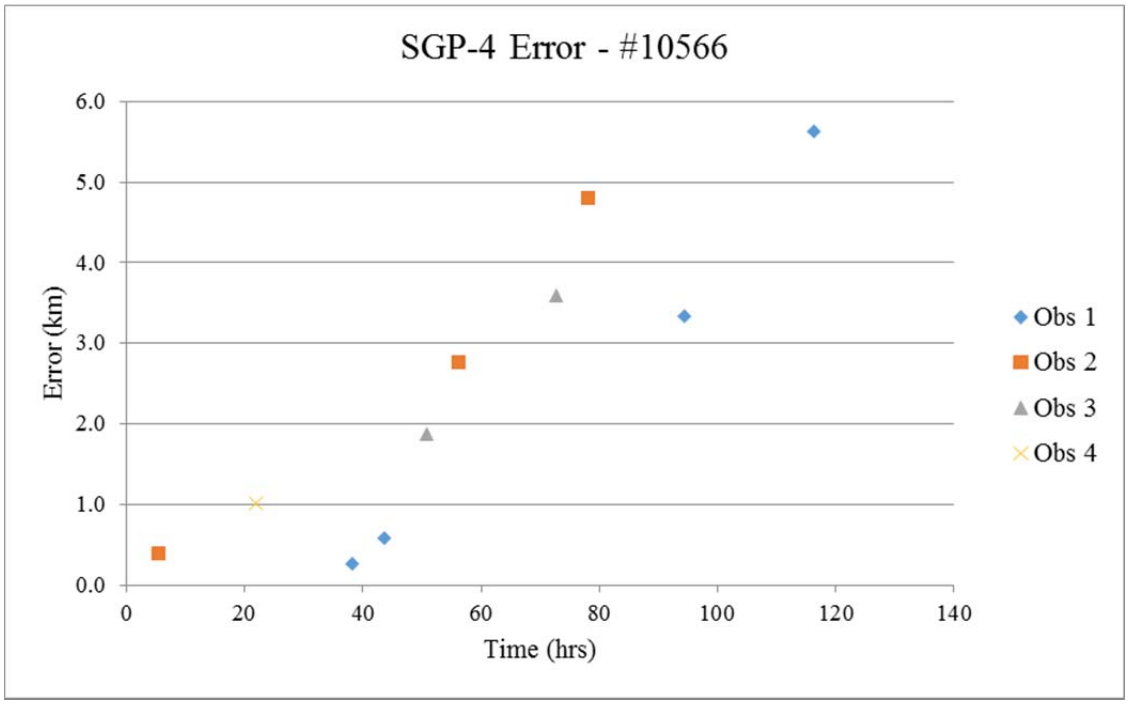

Figure 62. Error of the SGP-4 Propagator Over Time–#10566

FF. CATALOG NUMBER 10579–COSMOS 970 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.00-0.01 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 94. Two-Line Element for #10579 30NOV–7DEC15

Obs	TLE
1	1 10579U 77121W 15334.64704459 -.00000058 +00000-0 +30021-4 0 9999
	2 10579 065.6464 033.0501 0066284 303.7719 224.0457 13.32384616843199
2	1 10579U 77121W 15335.62248211 -.00000074 +00000-0 -11465-5 0 9998
	2 10579 065.6463 030.7945 0066355 303.4128 222.7592 13.32384500843326
3	1 10579U 77121W 15336.59533616 -.00000067 00000-0 13067-4 0 9991
	2 10579 65.6463 28.5449 0066424 303.0564 209.0797 13.32384519843704
4	1 10579U 77121W 15337.57402528 -.00000061 +00000-0 +25168-4 0 9996
	2 10579 065.6462 026.2818 0066498 302.6997 223.3868 13.32384581843587
5	1 10579U 77121W 15339.20312074 -.00000066 00000-0 14431-4 0 9990
	2 10579 65.6461 22.5147 0066599 302.1056 117.3850 13.32384598844057
6	1 10579U 77121W 15339.60069984 -.00000064 +00000-0 +18651-4 0 9999
	2 10579 065.6460 021.5954 0066626 301.9614 224.3826 13.32384619843852
7	1 10579U 77121W 15340.49045682 -.00000080 +00000-0 -14676-4 0 9999
	2 10579 065.6460 019.5379 0066681 301.6388 172.1222 13.32384506843974
8	1 10579U 77121W 15341.54935338 -.00000070 00000-0 58112-5 0 9994
	2 10579 65.6460 17.0893 0066749 301.2638 211.1359 13.32384589844367

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 95. Ephemeris Data Derived From TLEs for #10579

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	15 : 31 : 44.653	13.3238	0.0066284	65.6464	303.7719	33.0501	224.0457
2	1-Dec	14 : 56 : 22.454	13.3238	66355	65.6463	303.4128	30.7945	222.7592
3	2-Dec	14 : 17 : 17.044	13.3238	66424	65.6463	303.0564	28.5449	209.0797
4	3-Dec	13 : 46 : 35.784	13.3238	66498	65.6462	302.6997	26.2818	223.3868
5	5-Dec	4 : 52 : 29.632	13.3238	66599	65.6461	302.1056	22.5147	117.3850
6	5-Dec	14 : 25 : 0.466	13.3238	66626	65.6460	301.9614	21.5954	224.3826
7	6-Dec	11 : 46 : 15.469	13.3238	66681	65.6460	301.6388	19.5379	172.1222
8	7-Dec	13 : 11 : 4.132	13.3238	66749	65.6460	301.2638	17.0893	211.1359

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 96. Error of Propagated Ephemeris for #10579

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.160	314.000	23.41050
→3	0.106	589	46.75900
→4	0.118	942	70.24754
→5	0.261	1035	109.34583
→6	0.045	1604	118.88773
→7	0.049	1239	140.24189
→8	0.204	2105	165.65541
Obs 2→3	0.106	294	23.34850
→4	0.224	627	46.83704
→5	0.685	816	85.93533
→6	0.489	1288	95.47723
→7	0.805	1031	116.83139
→8	0.825	1807	142.24491
Obs 3→4	0.118	314	23.48854
→5	0.494	596	62.58683
→6	0.369	973	72.12873
→7	0.6	824	93.48290
→8	0.648	1510	118.89641
Obs 4→5	0.261	373	39.09829
→6	0.228	656	48.64019
→7	0.345	616	69.99436
→8	0.446	1211	95.40787
Obs 5→6	0.045	129	9.54190
→7	0.117	271	30.89607
→8	0.264	714	56.30958
Obs 6→7	0.049	187	21.35417
→8	0.207	592	46.76768
Obs 7→8	0.204	322	25.41352

Figure 63. Error of the Two-Body Propagator Over Time–#10579

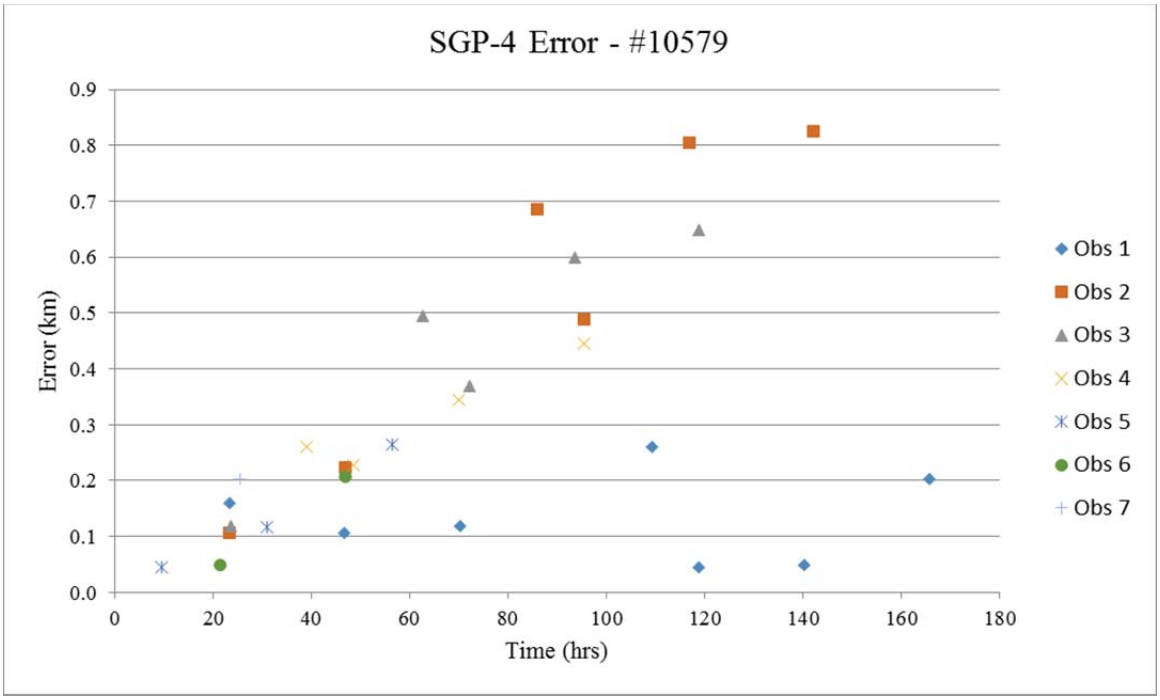

Figure 64. Error of the SGP-4 Propagator Over Time–#10579

GG. CATALOG NUMBER 12458–NOVA 1

This ephemeris data represents one of three samples for semi-major axes 7500–7600 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 97. Two-Line Element for #12458 30NOV–7DEC15

Obs	TLE
1	1 12458U 81044A 15335.86219775 +.00000087 +00000-0 +18709-3 0 9992
	2 12458 089.9766 123.2022 0015571 120.9115 343.0707 13.22928499667380
2	1 12458U 81044A 15336.16389328 .00000091 00000-0 19474-3 0 9993
	2 12458 89.9766 123.2016 0015579 120.1631 339.8247 13.22928497667702
3	1 12458U 81044A 15336.93291887 +.00000088 +00000-0 +18886-3 0 9992
	2 12458 089.9767 123.2000 0015612 118.2650 042.1194 13.22928526667521
4	1 12458U 81044A 15337.29738961 .00000084 00000-0 17948-3 0 9995
	2 12458 89.9767 123.1992 0015625 117.3736 337.8135 13.22928552667853
5	1 12458U 81044A 15337.90381707 +.00000068 +00000-0 +14045-3 0 9992
	2 12458 089.9767 123.1980 0015651 115.8674 345.7849 13.22928598667651
6	1 12458U 81044A 15338.88917251 .00000052 00000-0 10326-3 0 9990
	2 12458 89.9769 123.1959 0015679 113.4336 358.3008 13.22928761668063
7	1 12458U 81044A 15338.96532935 +.00000049 +00000-0 +94945-4 0 9997
	2 12458 089.9769 123.1957 0015682 113.2436 000.9811 13.22928762667796
8	1 12458U 81044A 15339.94863091 .00000049 00000-0 94441-4 0 9997
	2 12458 89.9770 123.1937 0015721 110.8756 3.6548 13.22928905668201
9	1 12458U 81044A 15341.00853876 .00000070 00000-0 14527-3 0 9997
	2 12458 89.9772 123.1915 0015735 108.2504 11.2151 13.22929031668347

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 98. Ephemeris Data Derived From TLEs for #12458

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	20 : 41 : 33.886	13.2293	0.0015571	89.9766	120.9115	123.2022	343.0707
2	2-Dec	3 : 56 : 0.379	13.2293	15579	89.9766	120.1631	123.2016	339.8247
3	2-Dec	22 : 23 : 24.190	13.2293	15612	89.9767	118.2650	123.2000	42.1194
4	3-Dec	7 : 8 : 14.462	13.2293	15625	89.9767	117.3736	123.1992	337.8135
5	3-Dec	21 : 41 : 29.795	13.2293	15651	89.9767	115.8674	123.1980	345.7849
6	4-Dec	21 : 20 : 24.505	13.2293	15679	89.9769	113.4336	123.1959	358.3008
7	4-Dec	23 : 10 : 4.456	13.2293	15682	89.9769	113.2436	123.1957	0.9811
8	5-Dec	22 : 46 : 1.711	13.2293	15721	89.9770	110.8756	123.1937	3.6548
9	7-Dec	0 : 12 : 17.749	13.2293	15735	89.9772	108.2504	123.1915	11.2151

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 99. Error of Propagated Ephemeris for #12458

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.093	110	7.24069
→3	0.195	389	25.69731
→4	0.331	522	34.44460
→5	0.407	742	48.99886
→6	0.492	1100	72.64739
→7	0.499	1127	74.47516
→8	0.736	1483	98.07440
→9	1.044	1866	123.51218
Obs 2→3	0.104	280	18.45661
→4	0.213	412	27.20391
→5	0.279	633	41.75817
→6	0.351	990	65.40670
→7	0.358	1018	67.23447
→8	0.582	1374	90.83370
→9	0.880	1757	116.27149
Obs 3→4	0.039	133	8.74730
→5	0.077	353	23.30156
→6	0.114	711	46.95009
→7	0.121	739	48.77785
→8	0.295	1095	72.37709
→9	0.542	1479	97.81488
Obs 4→5	0.030	220	14.55426
→6	0.061	578	38.20279
→7	0.068	606	40.03055
→8	0.213	963	63.62979
→9	0.432	1347	89.06758
Obs 5→6	0.039	358	23.64853
→7	0.040	386	25.47629
→8	0.123	743	49.07553
→9	0.282	1128	74.51332
Obs 6→7	0.008	28	1.82776
→8	0.137	372	25.42700
→9	0.305	757	50.86479
Obs 7→8	0.125	357	23.59924
→9	0.287	742	49.03703
Obs 8→9	0.200	385	25.43779

Figure 65. Error of the Two-Body Propagator Over Time–#12458

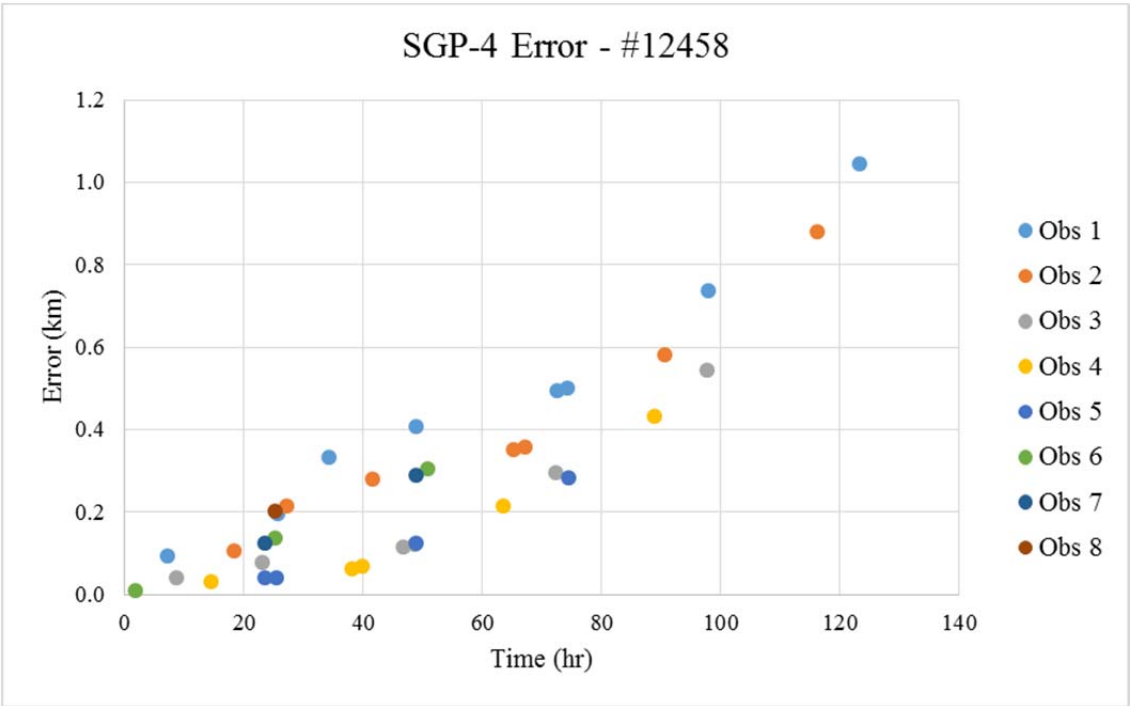

Figure 66. Error of the SGP-4 Propagator Over Time–#12458

HH. CATALOG NUMBER 12867–COSMOS 970 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.00-0.01 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 100. Two-Line Element for #12867 30NOV–7DEC15

Obs	TLE
1	1 12867U 77121AV 15334.23415836 +.00000028 +00000-0 +19088-3 0 9999 2 12867 065.9501 249.3043 0090864 240.6666 198.7337 13.35709281771703
2	1 12867U 77121AV 15336.77010454 -.00000008 00000-0 12311-3 0 9998 2 12867 65.9501 243.4749 0090727 239.5421 152.8701 13.35709595806607
3	1 12867U 77121AV 15337.15260685 -.00000012 +00000-0 +11566-3 0 9990 2 12867 065.9500 242.5957 0090696 239.3715 192.1391 13.35709589772096
4	1 12867U 77121AV 15338.87444814 -.00000036 00000-0 69399-4 0 9992 2 12867 65.9499 238.6377 0090576 238.6015 191.6468 13.35709678806880
5	1 12867U 77121AV 15338.95316447 -.00000045 +00000-0 +51253-4 0 9991 2 12867 065.9499 238.4567 0090570 238.5623 210.1594 13.35709599772338
6	1 12867U 77121AV 15339.92478894 -.00000052 +00000-0 +39081-4 0 9997 2 12867 065.9497 236.2232 0090517 238.1309 202.2318 13.35709650772467
7	1 12867U 77121AV 15340.97767234 -.00000051 00000-0 40469-4 0 9994 2 12867 65.9496 233.8029 0090463 237.6629 225.0391 13.35709632807162
8	1 12867U 77121AV 15341.94798863 -.00000046 +00000-0 +49825-4 0 9993 2 12867 065.9494 231.5725 0090395 237.2280 210.8246 13.35709626772739

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 101. Ephemeris Data Derived From TLEs for #12867

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	5 : 37 : 11.282	13.3571	0.0090864	65.9501	240.6666	249.3043	198.7337
2	2-Dec	18 : 28 : 57.032	13.3571	90727	65.9501	239.5421	243.4749	152.8701
3	3-Dec	3 : 39 : 45.232	13.3571	90696	65.9500	239.3715	242.5957	192.1391
4	4-Dec	20 : 59 : 12.319	13.3571	90576	65.9499	238.6015	238.6377	191.6468
5	4-Dec	22 : 52 : 33.410	13.3571	90570	65.9499	238.5623	238.4567	210.1594
6	5-Dec	22 : 11 : 41.764	13.3571	90517	65.9497	238.1309	236.2232	202.2318
7	6-Dec	23 : 27 : 50.890	13.3571	90463	65.9496	237.6629	233.8029	225.0391
8	7-Dec	22 : 45 : 6.218	13.3571	90395	65.9494	237.2280	231.5725	210.8246

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 102. Error of Propagated Ephemeris for #12867

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.240	770	60.86271
→3	0.215	608	70.04276
→4	0.203	869	111.36695
→5	0.099	884	113.25615
→6	0.258	1104	136.57513
→7	0.521	1303	161.84434
→8	0.969	1367	185.13193
Obs 2→3	0.023	80.2	9.18006
→4	0.115	395	50.50425
→5	0.074	410	52.39344
→6	0.103	616	75.71243
→7	0.157	812	100.98163
→8	0.339	898	124.26922
Obs 3→4	0.141	324	41.32419
→5	0.101	338	43.21338
→6	0.122	542	66.53237
→7	0.107	738	91.80157
→8	0.193	828	115.08916
Obs 4→5	0.058	15	1.88919
→6	0.033	206	25.20818
→7	0.07	406	50.47738
→8	0.084	506	73.76497
Obs 5→6	0.123	191	25.20818
→7	0.182	390	48.58819
→8	0.19	492	73.76497
Obs 6→7	0.048	203	25.26920
→8	0.072	310	48.55679
Obs 7→8	0.054	113	23.28759

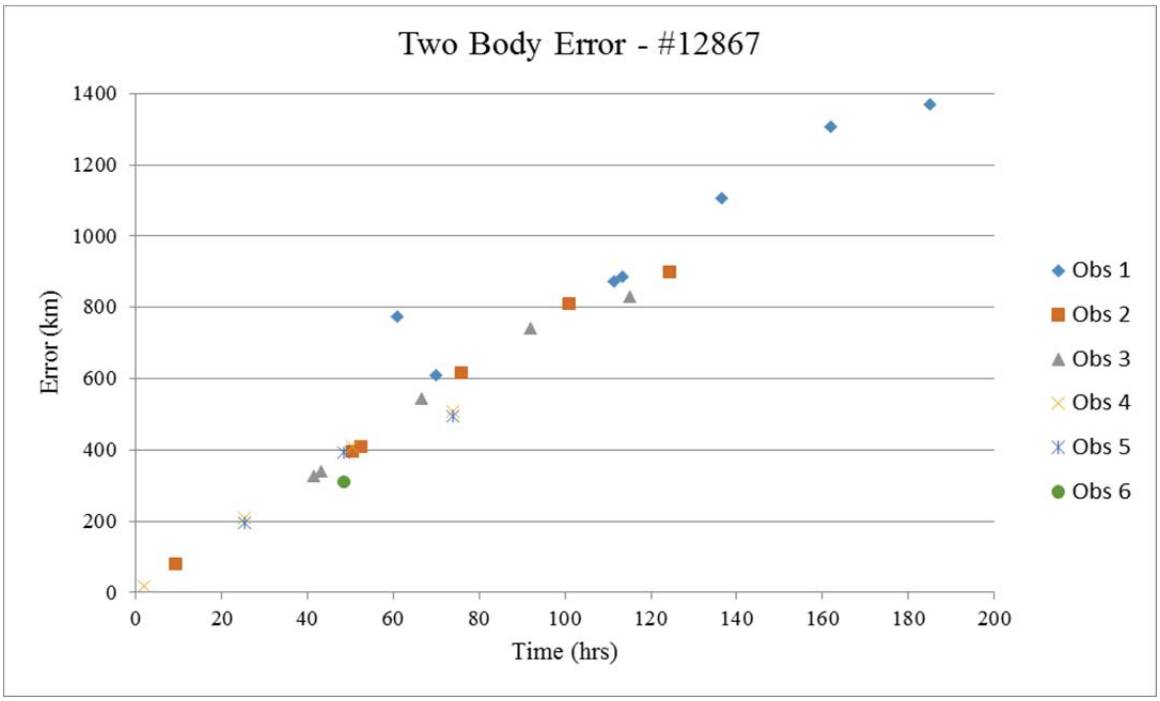

Figure 67. Error of the Two-Body Propagator Over Time–#12867

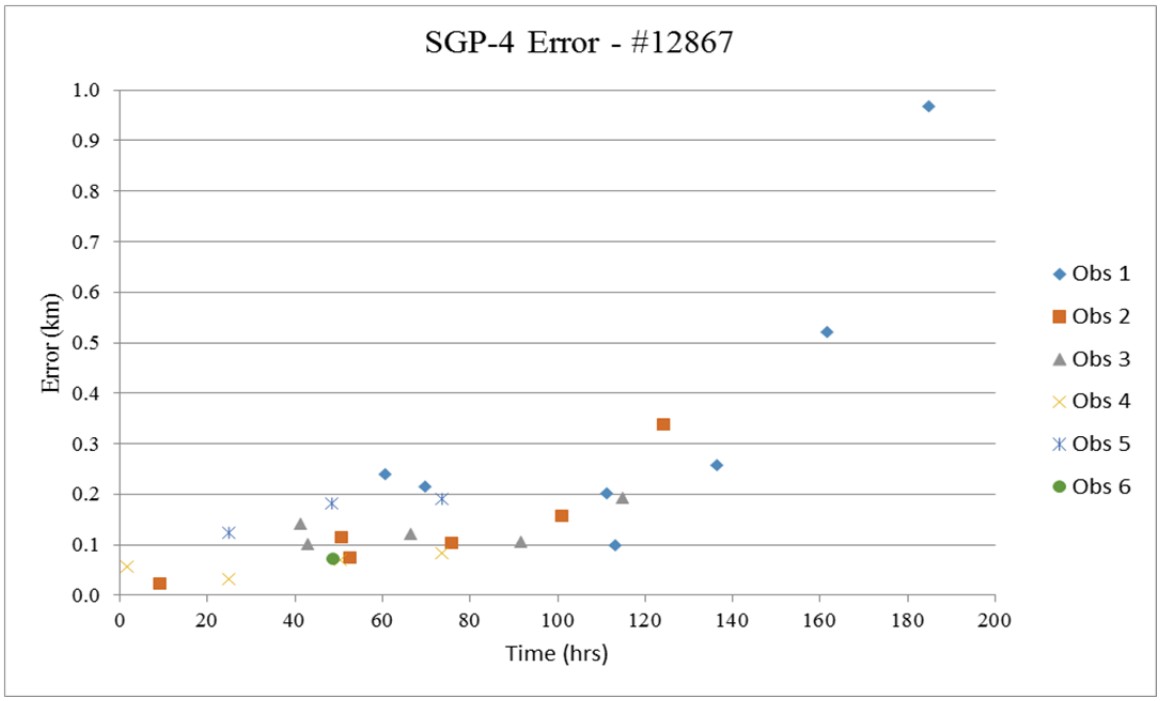

Figure 68. Error of the SGP-4 Propagator Over Time–#12867

II. CATALOG NUMBER 12942–COSMOS 970 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.01-0.02 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 103. Two-Line Element for #12942 30NOV–7DEC15

Obs	TLE
1	1 12942U 77121AZ 15334.70786567 +.00000021 +00000-0 +17493-3 0 9998
	2 12942 065.8312 074.7058 0108211 182.7057 329.5715 13.36501064678731
2	1 12942U 77121AZ 15335.45049162 .00000020 00000-0 17281-3 0 9998
	2 12942 65.8312 72.9883 0108149 182.3805 302.6278 13.36501185679049
3	1 12942U 77121AZ 15335.75696116 +.00000020 +00000-0 +17405-3 0 9996
	2 12942 065.8312 072.2795 0108119 182.2473 337.1685 13.36501238678875
4	1 12942U 77121AZ 15336.72892637 +.00000003 +00000-0 +14106-3 0 9996
	2 12942 065.8313 070.0317 0108034 181.8284 333.6578 13.36501368679005
5	1 12942U 77121AZ 15337.70106918 -.00000015 00000-0 10795-3 0 9999
	2 12942 65.8314 67.7834 0107947 181.4048 331.0060 13.36501444679349
6	1 12942U 77121AZ 15339.63921583 -.00000006 +00000-0 +12574-3 0 9993
	2 12942 065.8315 063.3010 0107764 180.5563 296.1719 13.36501812679393
7	1 12942U 77121AZ 15340.07623072 -.00000004 00000-0 12878-3 0 9990
	2 12942 65.8315 62.2903 0107716 180.3687 238.8148 13.36501918679660
8	1 12942U 77121AZ 15340.61185748 +.00000001 +00000-0 +13797-3 0 9990
	2 12942 065.8315 061.0515 0107666 180.1327 295.9224 13.36502044679524

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 104. Ephemeris Data Derived From TLEs for #12942

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	16 : 59 : 19.594	13.3650	0.0108211	65.8312	182.7057	74.7058	329.5715
2	1-Dec	10 : 48 : 42.476	13.3650	108149	65.8312	182.3805	72.9883	302.6278
3	1-Dec	18 : 10 : 1.444	13.3650	108119	65.8312	182.2473	72.2795	337.1685
4	2-Dec	17 : 29 : 39.238	13.3650	108034	65.8313	181.8284	70.0317	333.6578
5	3-Dec	16 : 49 : 32.377	13.3650	107947	65.8314	181.4048	67.7834	331.0060
6	5-Dec	15 : 20 : 28.248	13.3650	107764	65.8315	180.5563	63.3010	296.1719
7	6-Dec	1 : 49 : 46.334	13.3650	107716	65.8315	180.3687	62.2903	238.8148
8	6-Dec	14 : 41 : 4.486	13.3650	107666	65.8315	180.1327	61.0515	295.9224

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 105. Error of Propagated Ephemeris for #12942

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.075	173	17.82302
→3	0.115	320	25.17829
→4	0.201	607	48.50546
→5	0.291	897	71.83688
→6	0.508	1067	118.35240
→7	0.822	1280	128.84076
→8	0.630	1288	141.69580
Obs 2→3	0.038	96	7.35527
→4	0.133	329	30.68243
→5	0.219	674	54.01386
→6	0.467	905	100.52938
→7	0.765	1106	111.01774
→8	0.600	1124	123.87278
Obs 3→4	0.108	292	23.32717
→5	0.186	582	46.65859
→6	0.440	838	93.17411
→7	0.725	1033	103.66247
→8	0.572	1057	116.51751
Obs 4→5	0.095	291	23.33143
→6	0.403	627	69.84695
→7	0.675	804	80.33530
→8	0.608	844	93.19035
Obs 5→6	0.404	417	46.51552
→7	0.664	572	57.00388
→8	0.682	632	69.85892
Obs 6→7	0.144	106	10.48836
→8	0.216	210	23.34340
Obs 7→8	0.089	116	12.85504

Figure 69. Error of the Two-Body Propagator Over Time–#12942

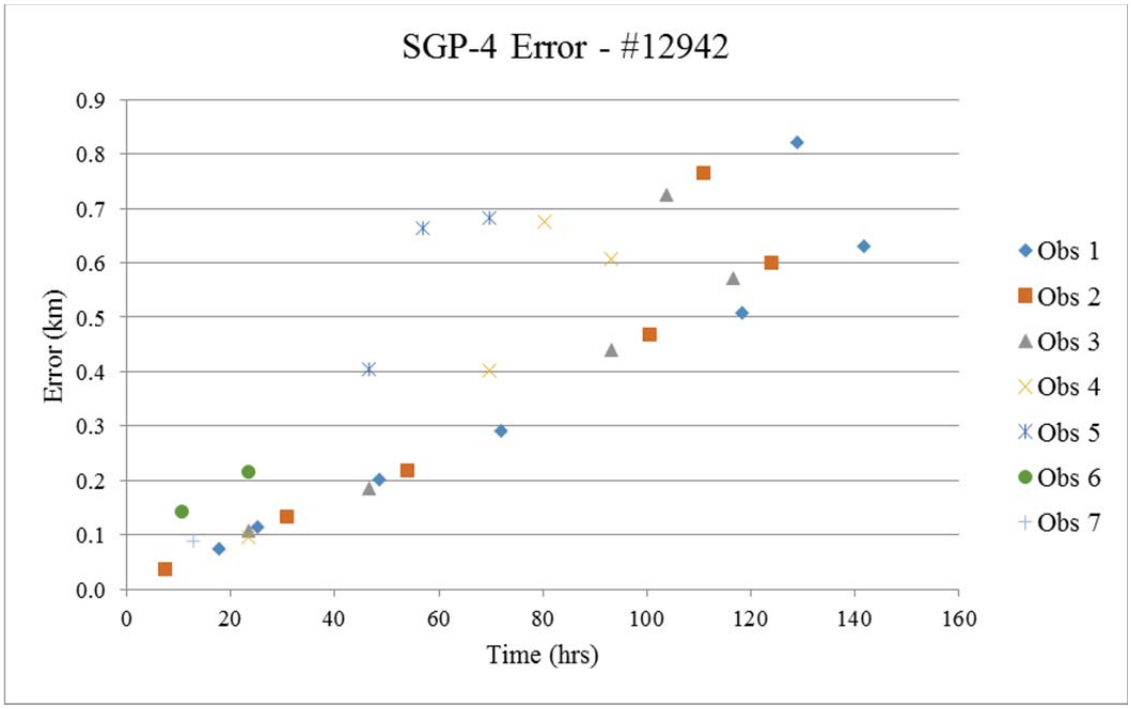

Figure 70. Error of the SGP-4 Propagator Over Time–#12942

JJ. CATALOG NUMBER 13132–N-1 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.02-0.03 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 106. Two-Line Element for #13132 30NOV–7DEC15

Obs	TLE
1	1 13132U 78018C 15334.81146275 -.00000030 +00000-0 +34828-4 0 9997
	2 13132 069.2058 321.7344 0210122 190.9792 240.7561 13.34763429839457
2	1 13132U 78018C 15335.33534988 -.00000036 +00000-0 +24707-4 0 9998
	2 13132 069.2058 320.6864 0210099 190.4341 238.1090 13.34763418839524
3	1 13132U 78018C 15336.09736168 -.00000043 00000-0 13513-4 0 9997
	2 13132 69.2058 319.1619 0210055 189.6401 299.6863 13.34763434839881
4	1 13132U 78018C 15336.38583428 -.00000039 +00000-0 +20353-4 0 9993
	2 13132 069.2058 318.5848 0210037 189.3397 245.8387 13.34763431839666
5	1 13132U 78018C 15337.36876325 -.00000025 +00000-0 +44336-4 0 9995
	2 13132 069.2059 316.6184 0209987 188.3137 288.9568 13.34763483839792
6	1 13132U 78018C 15339.00586623 -.00000024 00000-0 45675-4 0 9993
	2 13132 69.2060 313.3433 0209891 186.6043 235.4777 13.34763548840272
7	1 13132U 78018C 15339.30706169 -.00000023 +00000-0 +47115-4 0 9995
	2 13132 069.2060 312.7408 0209863 186.2902 242.7658 13.34763557840051
8	1 13132U 78018C 15340.59166817 -.00000042 +00000-0 +15114-4 0 9993
	2 13132 069.2061 310.1710 0209786 184.9510 295.4879 13.34763573840221
9	1 13132U 78018C 15341.04016102 -.00000044 00000-0 10507-4 0 9998
	2 13132 69.2061 309.2737 0209765 184.4823 290.5628 13.34763577840545

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 107. Ephemeris Data Derived From TLEs for #13132

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	19 : 28 : 30.382	13.3476	0.0210122	69.2058	190.9792	321.7344	240.7561
2	1-Dec	8 : 2 : 54.230	13.3476	210099	69.2058	190.4341	320.6864	238.1090
3	2-Dec	2 : 20 : 12.049	13.3476	210055	69.2058	189.6401	319.1619	299.6863
4	2-Dec	9 : 15 : 36.082	13.3476	210037	69.2058	189.3397	318.5848	245.8387
5	3-Dec	8 : 51 : 1.145	13.3476	209987	69.2059	188.3137	316.6184	288.9568
6	5-Dec	0 : 8 : 26.842	13.3476	209891	69.2060	186.6043	313.3433	235.4777
7	5-Dec	7 : 22 : 10.130	13.3476	209863	69.2060	186.2902	312.7408	242.7658
8	6-Dec	14 : 12 : 0.130	13.3476	209786	69.2061	184.9510	310.1710	295.4879
9	7-Dec	0 : 57 : 49.912	13.3476	209765	69.2061	184.4823	309.2737	290.5628

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 108. Error of Propagated Ephemeris for #13132

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.045	134	12.57329
→3	0.117	346	30.86157
→4	0.117	383	37.78492
→5	0.167	642	61.37521
→6	0.313	1092	100.66568
→7	0.291	1110	107.89437
→8	0.382	1491	138.72493
→9	0.373	1527	149.48876
Obs 2→3	0.082	205	18.28828
→4	0.091	256	25.21163
→5	0.159	509	48.80192
→6	0.318	958	88.09239
→7	0.317	982	95.32108
→8	0.458	1354	126.15164
→9	0.485	1397	136.91547
Obs 3→4	0.016	70	6.92334
→5	0.088	318	30.51364
→6	0.258	762	69.80411
→7	0.270	797	77.03280
→8	0.443	1156	107.86336
→9	0.492	1209	118.62718
Obs 4→5	0.074	245	23.59030
→6	0.236	687	62.88077
→7	0.248	726	70.10946
→8	0.412	1081	100.94001
→9	0.456	1138	111.70384
Obs 5→6	0.126	431	39.29047
→7	0.131	483	46.51916
→8	0.249	826	77.34972
→9	0.265	895	88.11355
Obs 6→7	0.024	76	7.22869
→8	0.166	404	38.05925
→9	0.197	494	48.82307
Obs 7→8	0.147	327	30.83056
→9	0.178	421	41.59438
Obs 8→9	0.045	109	10.76383

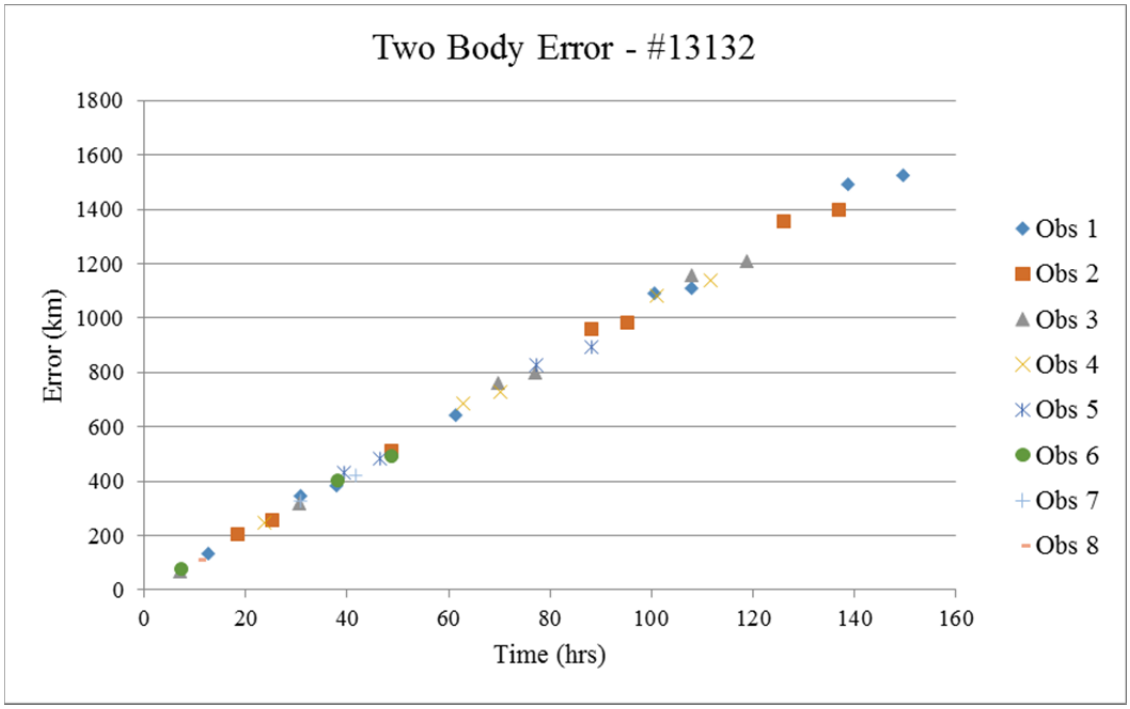

Figure 71. Error of the Two-Body Propagator Over Time–#13132

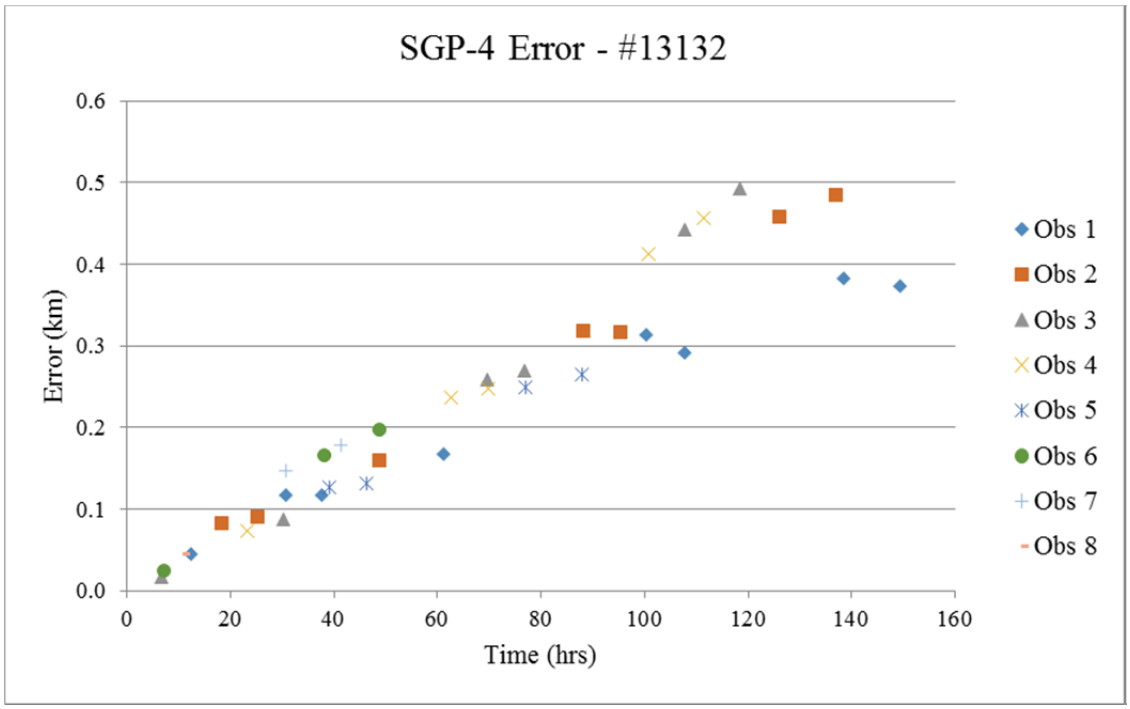

Figure 72. Error of the SGP-4 Propagator Over Time–#13132

KK. CATALOG NUMBER 13517–SL-8 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.05-0.06 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 109. Two-Line Element for #13517 30NOV–7DEC15

Obs	TLE
1	1 13517U 65020FF 15335.25565900 +.00000431 +00000-0 +44772-3 0 9994
	2 13517 055.5675 118.3324 0558597 056.8461 012.9159 13.35437364620861
2	1 13517U 65020FF 15336.22785414 .00000338 00000-0 37339-3 0 9993
	2 13517 55.5676 115.2130 0558561 58.4863 6.8250 13.35438088620990
3	1 13517U 65020FF 15337.27830626 .00000254 00000-0 30650-3 0 9991
	2 13517 55.5678 111.8426 0558532 60.2596 16.9625 13.35438793621132
4	1 13517U 65020FF 15338.78897279 .00000166 00000-0 23612-3 0 9997
	2 13517 55.5681 106.9958 0558479 62.8074 79.6269 13.35439742621337
5	1 13517U 65020FF 15339.76204188 +.00000202 +00000-0 +26459-3 0 9990
	2 13517 055.5682 103.8739 0558475 064.4497 077.7460 13.35440747621467
6	1 13517U 65020FF 15340.49860501 .00000208 00000-0 26934-3 0 9993
	2 13517 55.5684 101.5108 0558449 65.6917 18.8423 13.35441282621566
7	1 13517U 65020FF 15340.65083866 +.00000230 +00000-0 +28686-3 0 9993
	2 13517 055.5684 101.0224 0558453 065.9488 030.7201 13.35441510621584
8	1 13517U 65020FF 15341.54544302 .00000193 00000-0 25780-3 0 9999
	2 13517 55.5685 98.1522 0558421 67.4583 11.6159 13.35441894621709
9	1 13517U 65020FF 15341.62338032 +.00000197 +00000-0 +26103-3 0 9993
	2 13517 055.5685 097.9021 0558422 067.5899 026.3065 13.35441937621710

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 110. Ephemeris Data Derived From TLEs for #13517

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	6 : 8 : 8.938	13.3544	0.0558597	55.5675	56.8461	118.3324	12.9159
2	2-Dec	5 : 28 : 6.598	13.3544	558561	55.5676	58.4863	115.2130	6.8250
3	3-Dec	6 : 40 : 45.661	13.3544	558532	55.5678	60.2596	111.8426	16.9625
4	4-Dec	18 : 56 : 7.249	13.3544	558479	55.5681	62.8074	106.9958	79.6269
5	5-Dec	18 : 17 : 20.418	13.3544	558475	55.5682	64.4497	103.8739	77.7460
6	6-Dec	11 : 57 : 59.473	13.3544	558449	55.5684	65.6917	101.5108	18.8423
7	6-Dec	15 : 37 : 12.460	13.3544	558453	55.5684	65.9488	101.0224	30.7201
8	7-Dec	13 : 5 : 26.277	13.3544	558421	55.5685	67.4583	98.1522	11.6159
9	7-Dec	14 : 57 : 40.060	13.3544	558422	55.5685	67.5899	97.9021	26.3065

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 111. Error of Propagated Ephemeris for #13517

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.146	136	23.33268
→3	0.080	178	48.54353
→4	0.85	1001	84.79953
→5	1.376	1243	108.15319
→6	1.711	348	125.83070
→7	1.891	173	129.48431
→8	2.774	591	150.95482
→9	3.017	110	152.82531
Obs 2→3	0.144	88	25.21085
→4	0.179	733	61.46685
→5	0.282	986	84.82051
→6	0.26	265	102.49802
→7	0.345	159	106.15163
→8	0.645	477	127.62213
→9	0.831	86	129.49263
Obs 3→4	0.158	437	36.25600
→5	0.343	701	59.60965
→6	0.548	184	77.28717
→7	0.556	136	80.94078
→8	0.605	362	102.41128
→9	0.493	70	104.28178
Obs 4→5	0.322	279	23.35366
→6	0.543	86	41.03117
→7	0.617	88	44.68478
→8	0.908	215	66.15529
→9	0.835	53	68.02578
Obs 5→6	0.039	34	17.67752
→7	0.053	46	21.33112
→8	0.095	131	42.80163
→9	0.078	41	44.67212
Obs 6→7	0.061	8	3.65361
→8	0.070	73	25.12411
→9	0.039	28	26.99461
Obs 7→8	0.069	62	21.47050
→9	0.148	24	23.34100
Obs 8→9	0.055	2	1.87050

Figure 73. Error of the Two-Body Propagator Over Time–#13517

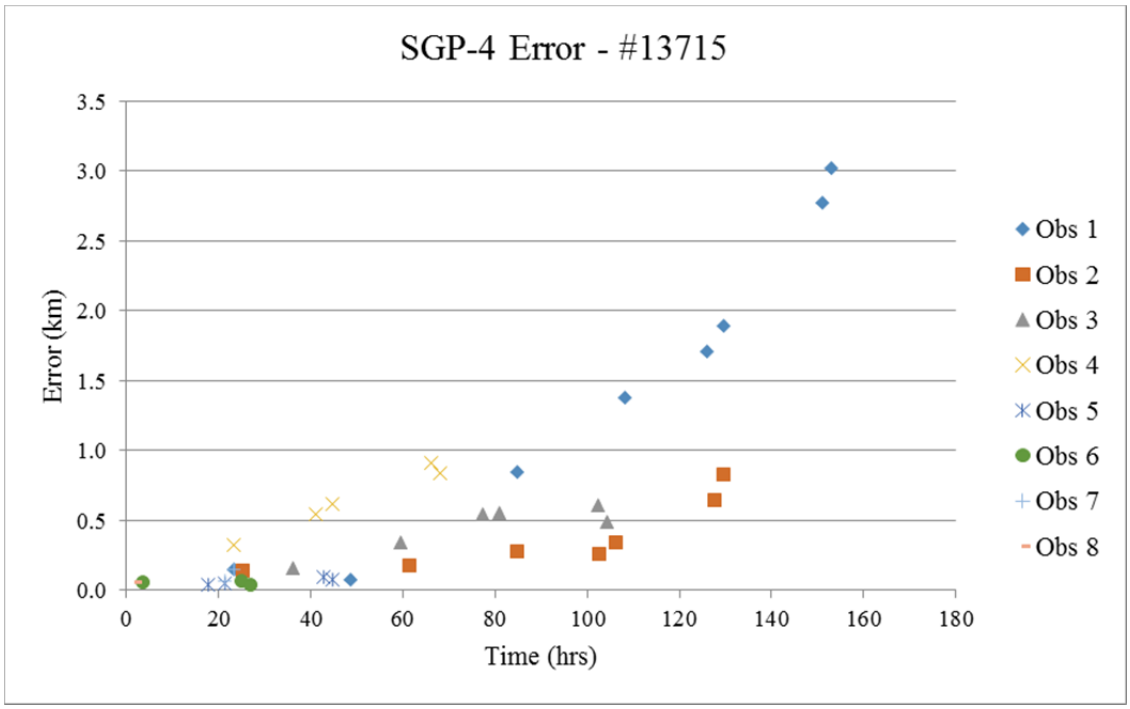

Figure 74. Error of the SGP-4 Propagator Over Time–#13517

LL. CATALOG NUMBER 15362–NOVA 3

This ephemeris data represents one of three samples for semi-major axes 7500–7600 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 112. Two-Line Element for #15362 30NOV–7DEC15

Obs	TLE
1	1 15362U 84110A 15334.73603509 +.00000070 +00000-0 +14790-3 0 9991
	2 15362 090.0375 052.7312 0031111 352.8507 180.6956 13.22698190502452
2	1 15362U 84110A 15335.86276763 .00000032 00000-0 57110-4 0 9996
	2 15362 90.0374 52.7353 0031023 349.6955 145.9241 13.22698271502876
3	1 15362U 84110A 15336.77314885 +.00000024 +00000-0 +36897-4 0 9995
	2 15362 090.0374 052.7385 0030953 347.1296 160.9563 13.22698378502729
4	1 15362U 84110A 15337.75717196 +.00000035 +00000-0 +63852-4 0 9999
	2 15362 090.0374 052.7420 0030884 344.3478 166.6623 13.22698445502852
5	1 15362U 84110A 15338.81038340 .00000053 00000-0 10724-3 0 9993
	2 15362 90.0374 52.7458 0030801 341.3852 141.8139 13.22698495503263
6	1 15362U 84110A 15339.79225888 +.00000053 +00000-0 +10702-3 0 9992
	2 15362 090.0373 052.7493 0030722 338.6191 137.2851 13.22698561503127
7	1 15362U 84110A 15340.85525281 .00000037 00000-0 67998-4 0 9993
	2 15362 90.0372 52.7530 0030642 335.6038 159.0460 13.22698676503536

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 113. Ephemeris Data Derived From TLEs for #15362

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	17 : 39 : 53.432	13.2270	0.0031111	90.0375	352.8507	52.7312	180.6956
2	1-Dec	20 : 42 : 23.123	13.2270	31023	90.0374	349.6955	52.7353	145.9241
3	2-Dec	18 : 33 : 20.061	13.2270	30953	90.0374	347.1296	52.7385	160.9563
4	3-Dec	18 : 10 : 19.657	13.2270	30884	90.0374	344.3478	52.7420	166.6623
5	4-Dec	19 : 26 : 57.126	13.2270	30801	90.0374	341.3852	52.7458	141.8139
6	5-Dec	19 : 0 : 51.167	13.2270	30722	90.0373	338.6191	52.7493	137.2851
7	6-Dec	20 : 31 : 33.843	13.2270	30642	90.0372	335.6038	52.7530	159.0460

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 114. Error of Propagated Ephemeris for #15362

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.043	411	27.04158
→3	0.105	743	48.89073
→4	0.279	1102	72.50728
→5	0.621	1485	97.78436
→6	0.825	1841	121.34937
→7	0.829	2226	146.86123
Obs 2→3	0.047	332	21.84915
→4	0.175	692	45.46570
→5	0.365	1075	70.74278
→6	0.418	1432	94.30779
→7	0.301	1819	119.81964
Obs 3→4	0.171	359	23.61655
→5	0.362	743	48.89363
→6	0.422	1101	72.45864
→7	0.300	1488	97.97050
Obs 4→5	0.189	384	25.27707
→6	0.280	742	48.84209
→7	0.220	1130	74.35394
Obs 5→6	0.094	358	23.56501
→7	0.101	746	49.07687
Obs 6→7	0.058	388	25.51185

Figure 75. Error of the Two-Body Propagator Over Time–#15362

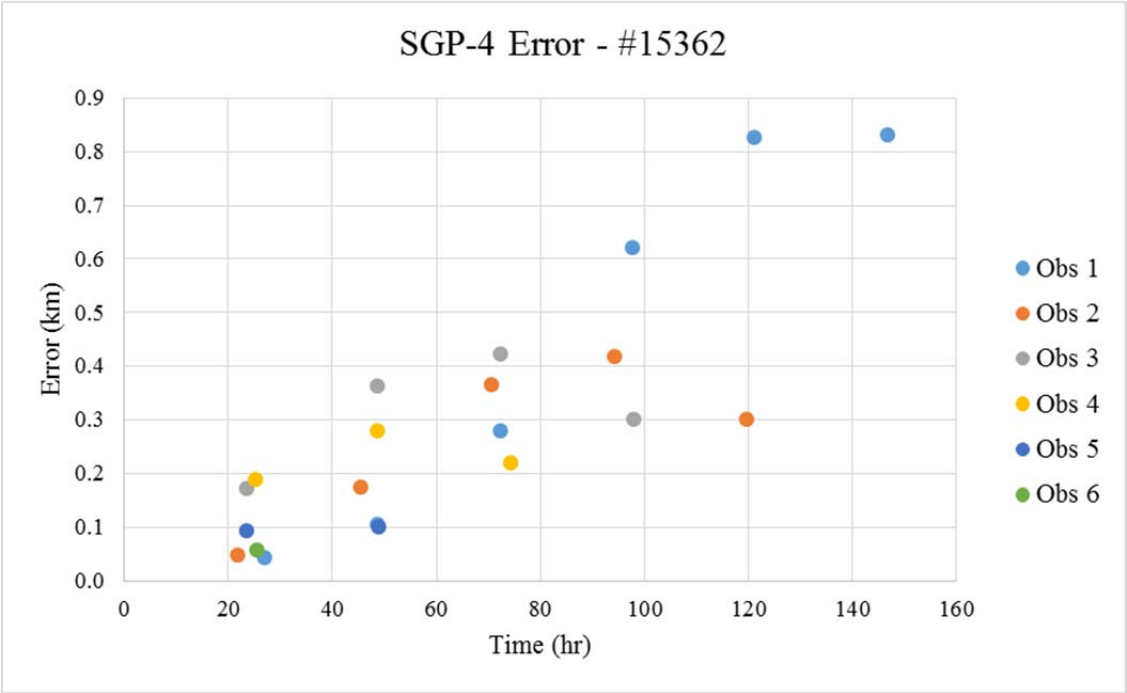

Figure 76. Error of the SGP-4 Propagator Over Time–#15362

MM. CATALOG NUMBER 17070–POLAR BEAR

This ephemeris data represents one of three samples for semi-major axes 7300–7400 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 115. Two-Line Element for #17070 30NOV–7DEC15

Obs	TLE
1	1 17070U 86088A 15334.18487748 +.00000064 +00000-0 +54982-4 0 9990
	2 17070 089.5433 354.2567 0039180 012.6060 030.5185 13.74679394456131
2	1 17070U 86088A 15335.12861689 .00000066 00000-0 57042-4 0 9997
	2 17070 89.5432 354.2112 0039072 9.7964 20.9046 13.74679538456539
3	1 17070U 86088A 15335.65988036 +.00000063 +00000-0 +54587-4 0 9999
	2 17070 089.5432 354.1856 0039021 008.1971 130.0435 13.74679574456331
4	1 17070U 86088A 15336.53870074 .00000065 00000-0 56821-4 0 9994
	2 17070 89.5432 354.1433 0038926 5.5592 159.1795 13.74679670456726
5	1 17070U 86088A 15336.67885703 +.00000063 +00000-0 +54722-4 0 9990
	2 17070 089.5432 354.1365 0038908 005.1412 132.7871 13.74679669456479
6	1 17070U 86088A 15337.69728245 .00000068 00000-0 59445-4 0 9992
	2 17070 89.5431 354.0874 0038805 2.0733 132.8165 13.74679788456884
7	1 17070U 86088A 15338.04432887 +.00000068 +00000-0 +59662-4 0 9997
	2 17070 089.5431 354.0707 0038772 001.0240 050.2993 13.74679824456663
8	1 17070U 86088A 15338.99298296 .00000076 00000-0 67771-4 0 9994
	2 17070 89.5430 354.0249 0038666 358.1684 65.0400 13.74679974457061
9	1 17070U 86088A 15339.66307244 +.00000082 +00000-0 +73839-4 0 9992
	2 17070 089.5430 353.9926 0038596 356.1343 141.2249 13.74680069456887
10	1 17070U 86088A 15340.01020189 .00000083 00000-0 75629-4 0 9993
	2 17070 89.5429 353.9759 0038560 355.0825 59.1212 13.74680117457201
11	1 17070U 86088A 15341.02853446 .00000092 00000-0 84631-4 0 9998
	2 17070 89.5428 353.9268 0038458 351.9914 58.7163 13.74680289457340

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 116. Ephemeris Data Derived From TLEs for #17070

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	4 : 26 : 13.414	13.7468	0.003918	89.5433	12.6060	354.2567	30.5185
2	1-Dec	3 : 5 : 12.499	13.7468	39072	89.5432	9.7964	354.2112	20.9046
3	1-Dec	15 : 50 : 13.663	13.7468	39021	89.5432	8.1971	354.1856	130.0435
4	2-Dec	12 : 55 : 43.744	13.7468	38926	89.5432	5.5592	354.1433	159.1795
5	2-Dec	16 : 17 : 33.247	13.7468	38908	89.5432	5.1412	354.1365	132.7871
6	3-Dec	16 : 44 : 5.204	13.7468	38805	89.5431	2.0733	354.0874	132.8165
7	4-Dec	1 : 3 : 50.014	13.7468	38772	89.5431	1.0240	354.0707	50.2993
8	4-Dec	23 : 49 : 53.728	13.7468	38666	89.5430	358.1684	354.0249	65.0400
9	5-Dec	15 : 54 : 49.459	13.7468	38596	89.5430	356.1343	353.9926	141.2249
10	6-Dec	0 : 14 : 41.443	13.7468	38560	89.5429	355.0825	353.9759	59.1212
11	7-Dec	0 : 41 : 5.377	13.7468	38458	89.5428	351.9914	353.9268	58.7163

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 117. Error of Propagated Ephemeris for #17070

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.084	364	22.64975
→3	0.172	573	35.40007
→4	0.207	915	56.49176
→5	0.288	968	59.85551
→6	0.416	1363	84.29772
→7	0.502	1490	92.62683
→8	0.657	1855	115.39453
→9	0.615	2122	131.47668
→10	0.774	2244	139.80779
→11	0.866	2633	164.24777
Obs 2→3	0.12	206	12.75032
→4	0.164	548	33.84201
→5	0.234	602	37.20576
→6	0.389	998	61.64797
→7	0.458	1126	69.97709
→8	0.63	1493	92.74479
→9	0.64	1758	108.82693
→10	0.777	1883	117.15804
→11	0.898	2273	141.59802
Obs 3→4	0.086	342	21.09169
→5	0.129	396	24.45544
→6	0.27	791	48.89765
→7	0.333	921	57.22676
→8	0.48	1288	79.99446
→9	0.499	1553	96.07661
→10	0.613	1679	104.40772
→11	0.713	2069	128.84770

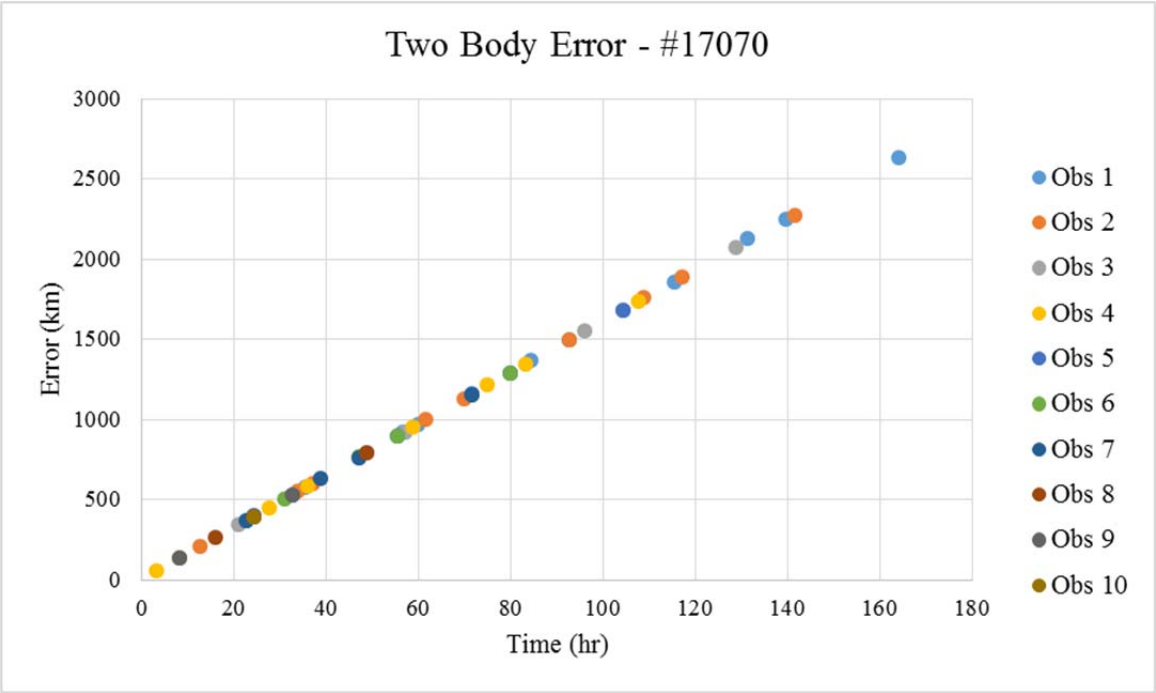

Figure 77. Error of the Two-Body Propagator Over Time–#17070

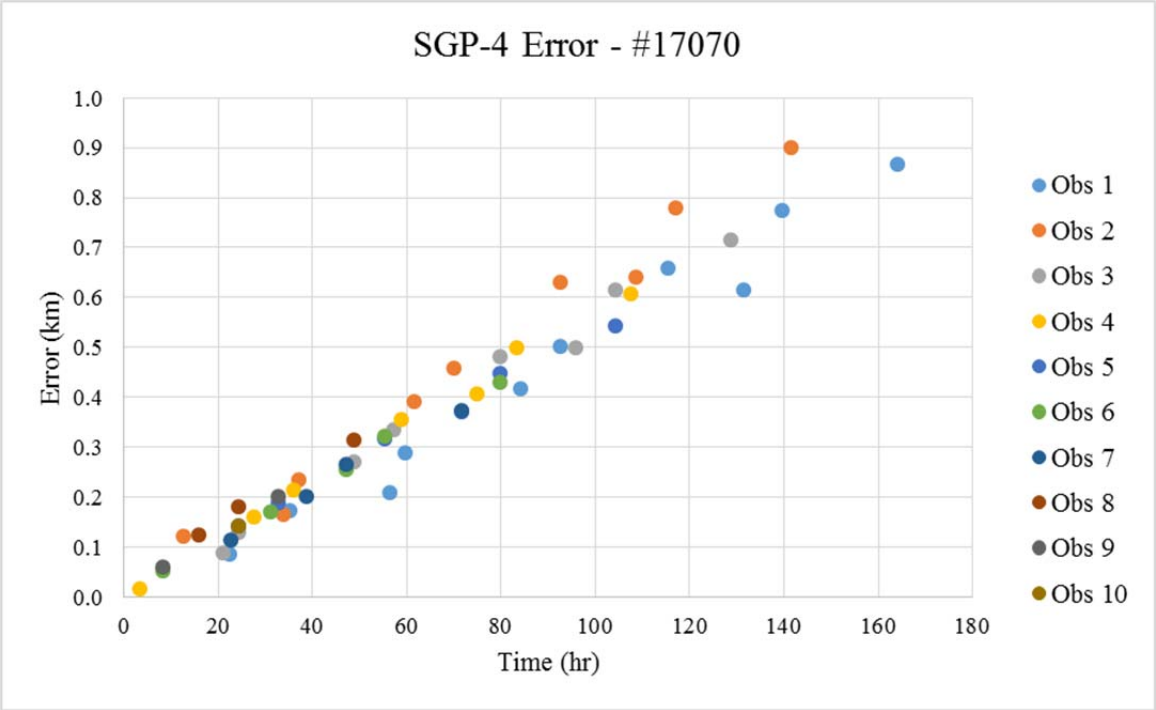

Figure 78. Error of the SGP-4 Propagator Over Time–#17070

NN. CATALOG NUMBER 18431–COSMOS 252 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.08-0.09 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 118. Two-Line Element for #18431 30NOV–7DEC15

Obs	TLE
1	1 18431U 68097EJ 15334.83503226 +.00000657 +00000-0 +24225-3 0 9998
	2 18431 062.3469 271.1731 0887533 070.2319 299.2127 13.16490670940908
2	1 18431U 68097EJ 15335.82246518 +.00000563 +00000-0 +21303-3 0 9996
	2 18431 062.3471 268.6347 0887530 070.4329 299.0255 13.16491633941030
3	1 18431U 68097EJ 15337.18967797 .00000446 00000-0 17696-3 0 9996
	2 18431 62.3471 265.1196 0887539 70.7111 298.7663 13.16493085941600
4	1 18431U 68097EJ 15338.93666923 +.00000323 +00000-0 +13906-3 0 9991
	2 18431 062.3471 260.6281 0887554 071.0652 298.4360 13.16494968941440
5	1 18431U 68097EJ 15339.31644968 .00000383 00000-0 15741-3 0 9994
	2 18431 62.3472 259.6520 0887575 71.1420 298.3646 13.16495780941889
6	1 18431U 68097EJ 15339.92409803 +.00000354 +00000-0 +14852-3 0 9998
	2 18431 062.3471 258.0897 0887579 071.2656 298.2492 13.16496404941572
7	1 18431U 68097EJ 15340.75961412 +.00000392 +00000-0 +16013-3 0 9993
	2 18431 062.3470 255.9415 0887579 071.4353 298.0907 13.16497568941682
8	1 18431U 68097EJ 15341.36726185 .00000364 00000-0 15141-3 0 9997
	2 18431 62.3469 254.3793 0887573 71.5579 297.9760 13.16498084942159

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 119. Ephemeris Data Derived From TLEs for #18431

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	20 : 2 : 26.787	13.1649	0.0887533	62.3469	70.2319	271.1731	299.2127
2	1-Dec	19 : 44 : 20.992	13.1649	887530	62.3471	70.4329	268.6347	299.0255
3	3-Dec	4 : 33 : 8.177	13.1649	887539	62.3471	70.7111	265.1196	298.7663
4	4-Dec	22 : 28 : 48.221	13.1649	887554	62.3471	71.0652	260.6281	298.4360
5	5-Dec	7 : 35 : 41.252	13.1650	887575	62.3472	71.1420	259.6520	298.3646
6	5-Dec	22 : 10 : 42.070	13.1650	887579	62.3471	71.2656	258.0897	298.2492
7	6-Dec	18 : 13 : 50.660	13.1650	887579	62.3470	71.4353	255.9415	298.0907
8	7-Dec	8 : 48 : 51.424	13.1650	887573	62.3469	71.5579	254.3793	297.9760

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 120. Error of Propagated Ephemeris for #18431

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.186	312	23.69839
→3	0.439	744	56.51150
→4	1.074	1297	98.43929
→5	1.319	1416	107.55402
→6	1.769	1614	122.13758
→7	2.605	1902	142.18996
→8	3.342	2060	156.77351
Obs 2→3	0.28	432	32.81311
→4	0.579	985	74.74090
→5	0.571	1104	83.85563
→6	0.55	1303	98.43919
→7	0.451	1591	118.49157
→8	0.461	1750	133.07512
Obs 3→4	0.833	552	41.92779
→5	0.98	672	51.04252
→6	1.228	871	65.62608
→7	1.477	1160	85.67847
→8	1.621	1319	100.26201
Obs 4→5	0.18	120	9.11473
→6	0.512	320	23.69829
→7	0.953	608	43.75068
→8	1.286	768	58.33422
Obs 5→6	0.188	200	14.58356
→7	0.397	488	34.63595
→8	0.534	648	49.21949
Obs 6→7	0.216	289	20.05239
→8	0.37	449	34.63593
Obs 7→8	0.059	192	14.58355

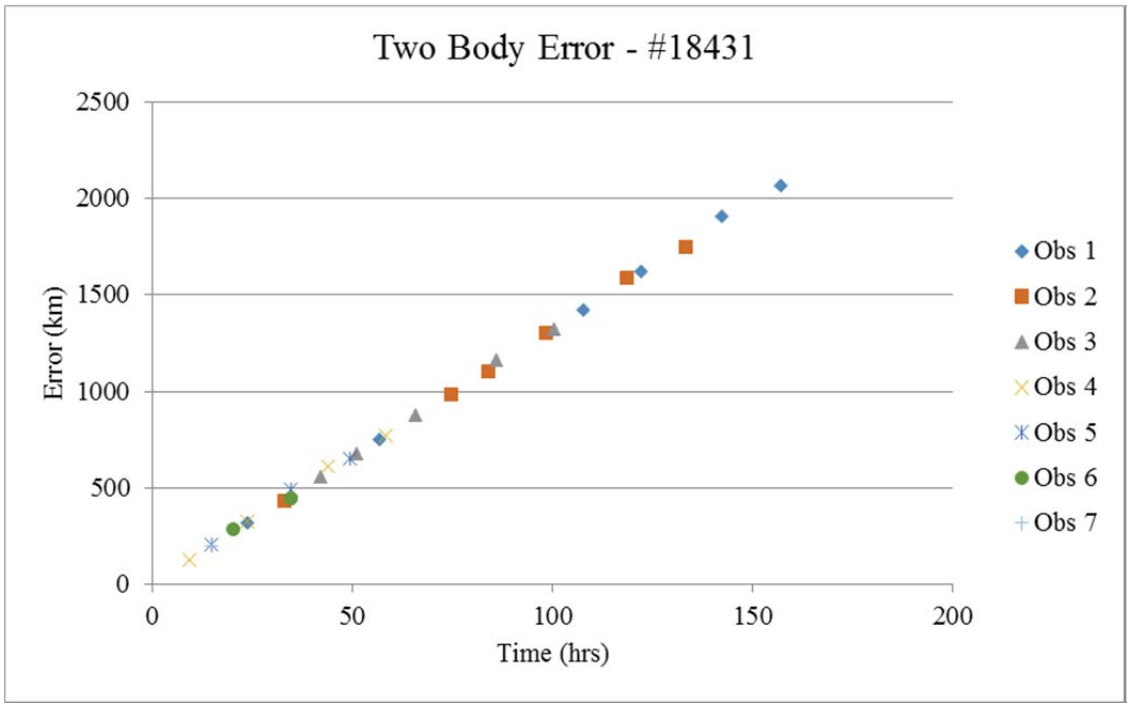

Figure 79. Error of the Two-Body Propagator Over Time–#18431

Figure 80. Error of the SGP-4 Propagator Over Time–#18431

OO. CATALOG NUMBER 18665–COSMOS 1900

This ephemeris data represents one of three samples for inclinations 60–70 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 121. Two-Line Element for #18665 30NOV–7DEC15

Obs	TLE
1	1 18665U 87101A 15334.43699871 +.00000019 +00000-0 +28721-4 0 9990
	2 18665 066.0845 333.0524 0043691 306.4590 053.2491 14.54352747488261
2	1 18665U 87101A 15335.12467052 .00000009 00000-0 26388-4 0 9997
	2 18665 66.0845 331.1347 0043733 306.1049 53.6010 14.54352879488353
3	1 18665U 87101A 15335.53727362 +.00000024 +00000-0 +29868-4 0 9998
	2 18665 066.0845 329.9841 0043763 305.9083 053.7964 14.54353036488428
4	1 18665U 87101A 15336.08741100 +.00000026 +00000-0 +30366-4 0 9992
	2 18665 066.0845 328.4499 0043792 305.6259 054.0771 14.54353192488507
5	1 18665U 87101A 15337.18768576 .00000014 00000-0 27389-4 0 9998
	2 18665 66.0845 325.3816 0043860 305.0768 54.6227 14.54353347488651
6	1 18665U 87101A 15337.94412461 +.00000001 +00000-0 +24450-4 0 9993
	2 18665 066.0845 323.2721 0043909 304.6984 054.9988 14.54353429488773
7	1 18665U 87101A 15338.90686478 -.00000002 +00000-0 +23858-4 0 9994
	2 18665 066.0846 320.5874 0043969 304.2174 055.4768 14.54353615488911
8	1 18665U 87101A 15339.18193335 -.00000005 00000-0 23043-4 0 9999
	2 18665 66.0846 319.8203 0043984 304.0811 55.6123 14.54353654488944
9	1 18665U 87101A 15339.93837186 +.00000008 +00000-0 +26027-4 0 9998
	2 18665 066.0846 317.7108 0044030 303.7013 055.9898 14.54353922489062
10	1 18665U 87101A 15340.35097468 .00000015 00000-0 27820-4 0 9997
	2 18665 66.0847 316.5602 0044060 303.4911 56.1987 14.54354036489111
11	1 18665U 87101A 15340.96987879 +.00000017 +00000-0 +28197-4 0 9998
	2 18665 066.0847 314.8343 0044092 303.1844 056.5036 14.54354222489218
12	1 18665U 87101A 15341.38248152 .00000023 00000-0 29647-4 0 9997
	2 18665 66.0847 313.6837 0044121 302.9805 56.7062 14.54354337489263

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 122. Ephemeris Data Derived From TLEs for #18665

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	10 : 29 : 16.689	14.5435	0.0043691	66.0845	306.4590	333.0524	53.2491
2	1-Dec	2 : 59 : 31.533	14.5435	43733	66.0845	306.1049	331.1347	53.6010
3	1-Dec	12 : 53 : 40.441	14.5435	43763	66.0845	305.9083	329.9841	53.7964
4	2-Dec	2 : 5 : 52.310	14.5435	43792	66.0845	305.6259	328.4499	54.0771
5	3-Dec	4 : 30 : 16.050	14.5435	43860	66.0845	305.0768	325.3816	54.6227
6	3-Dec	22 : 39 : 32.366	14.5435	43909	66.0845	304.6984	323.2721	54.9988
7	4-Dec	21 : 45 : 53.117	14.5435	43969	66.0846	304.2174	320.5874	55.4768
8	5-Dec	4 : 21 : 59.041	14.5435	43984	66.0846	304.0811	319.8203	55.6123
9	5-Dec	22 : 31 : 15.329	14.5435	44030	66.0846	303.7013	317.7108	55.9898
10	6-Dec	8 : 25 : 24.212	14.5435	44060	66.0847	303.4911	316.5602	56.1987
11	6-Dec	23 : 16 : 37.527	14.5435	44092	66.0847	303.1844	314.8343	56.5036
12	7-Dec	9 : 10 : 46.403	14.5435	44121	66.0847	302.9805	313.6837	56.7062

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 123. Error of Propagated Ephemeris for #18665

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.113	262	16.50412
→3	0.179	419	26.40660
→4	0.270	628	39.60989
→5	0.452	1046	66.01649
→6	0.598	1333	84.17102
→7	0.775	1697	107.27679
→8	0.825	1801	113.87843
→9	0.947	2087	132.03296
→10	1.025	2242	141.93542
→11	1.128	2474	156.78912
→12	1.206	2628	166.69159
Obs 2→3	0.069	157	9.90247
→4	0.160	366	23.10577
→5	0.340	785	49.51237
→6	0.478	1072	67.66690
→7	0.639	1437	90.77266
→8	0.684	1541	97.37431
→9	0.800	1827	115.52883
→10	0.869	1983	125.43130
→11	0.962	2216	140.28500
→12	1.030	2370	150.18746
Obs 3→4	0.091	209	13.20330
→5	0.290	628	39.60989
→6	0.455	916	57.76442
→7	0.650	1280	80.87019
→8	0.701	1384	87.47183
→9	0.828	1672	105.62636
→10	0.915	1827	115.52883
→11	1.024	2060	130.38252
→12	1.111	2215	140.28499
Obs 4→5	0.213	419	26.40659
→6	0.387	707	44.56113
→7	0.591	1071	67.66689
→8	0.644	1176	74.26854
→9	0.774	1463	92.42306
→10	0.865	1619	102.32553
→11	0.979	1853	117.17923
→12	1.071	2008	127.08169

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 5→6	0.145	288	18.15453
→7	0.308	654	41.26030
→8	0.352	758	47.86194
→9	0.468	1046	66.01647
→10	0.538	1203	75.91893
→11	0.630	1437	90.77263
→12	0.699	1593	100.67510
Obs 6→7	0.150	366	23.10576
→8	0.195	471	29.70741
→9	0.324	759	47.86193
→10	0.389	915	57.76440
→11	0.492	1150	72.61810
→12	0.559	1306	82.52057
Obs 7→8	0.049	105	6.60165
→9	0.185	393	24.75617
→10	0.250	549	34.65864
→11	0.361	784	49.51234
→12	0.431	941	59.41480
Obs 8→9	0.138	288	18.15452
→10	0.203	445	28.05699
→11	0.319	680	42.91069
→12	0.390	837	52.81316
Obs 9→10	0.066	157	9.90247
→11	0.164	392	24.75617
→12	0.231	549	34.65863
Obs 10→11	0.101	235	14.85370
→12	0.167	392	24.75616
Obs 11→12	0.068	157	9.90247

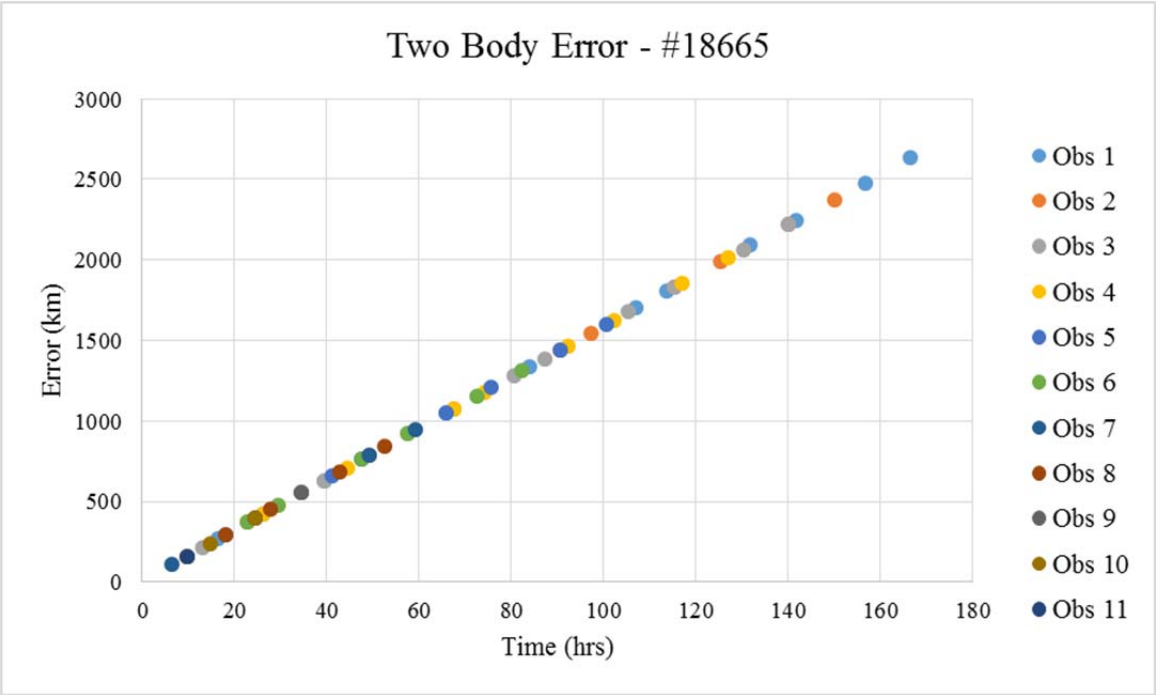

Figure 81. Error of the Two-Body Propagator Over Time–#18665

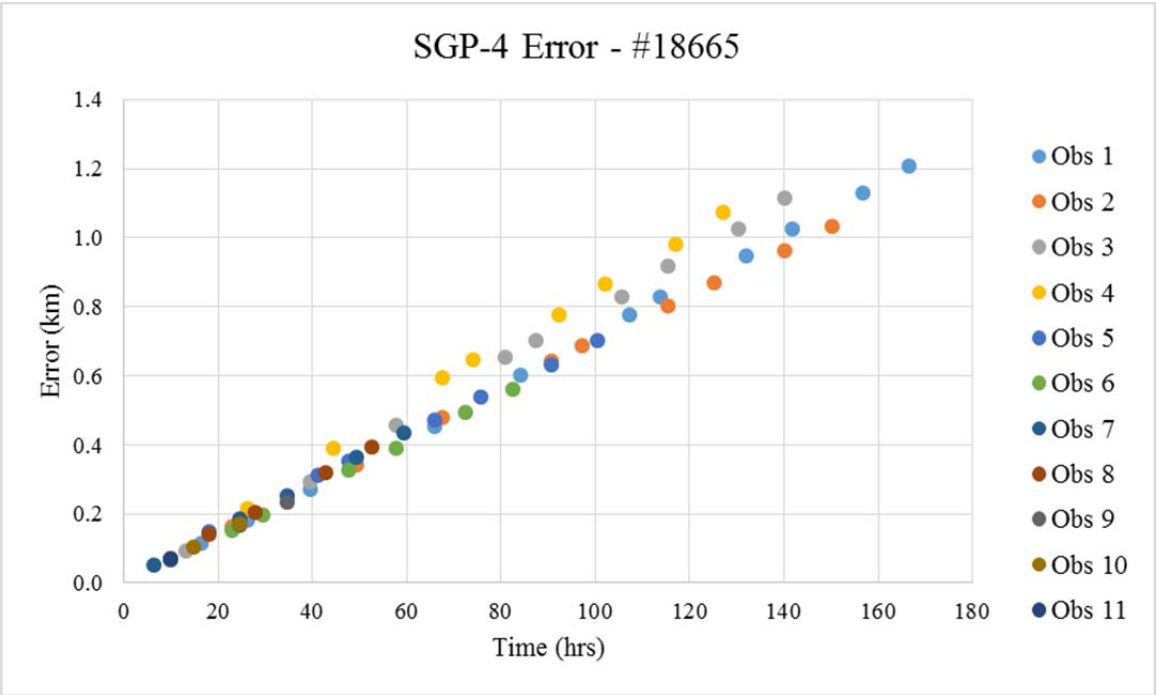

Figure 82. Error of the SGP-4 Propagator Over Time–#18665

PP. CATALOG NUMBER 19024–COSMOS 397 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.05-0.06 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 124. Two-Line Element for #19024 30NOV–7DEC15

Obs	TLE
1	1 19024U 71015DN 15336.65388619 .00000550 00000-0 72394-3 0 9992
	2 19024 66.2785 52.0155 0517316 271.5886 245.0963 13.22820685336064
2	1 19024U 71015DN 15337.63657712 +.00000539 +00000-0 +71017-3 0 9992
	2 19024 066.2784 049.8236 0517468 271.0807 244.8060 13.22821671336200
3	1 19024U 71015DN 15338.61928556 .00000553 00000-0 72655-3 0 9993
	2 19024 66.2785 47.6322 0517395 270.5641 244.6166 13.22822967336329
4	1 19024U 71015DN 15339.60204522 +.00000574 +00000-0 +75153-3 0 9992
	2 19024 066.2784 045.4403 0517473 270.0539 244.6662 13.22824181336468
5	1 19024U 71015DN 15340.18044172 .00000568 00000-0 74424-3 0 9993
	2 19024 66.2784 44.1504 0517455 269.7516 119.0818 13.22824815336536
6	1 19024U 71015DN 15340.58461845 +.00000583 +00000-0 +76240-3 0 9992
	2 19024 066.2784 043.2490 0517488 269.5415 243.8344 13.22825333336594

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 125. Ephemeris Data Derived From TLEs for #19024

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	2-Dec	15 : 41 : 35.767	13.2282	0.0517316	66.2785	271.5886	52.0155	245.0963
2	3-Dec	15 : 16 : 40.263	13.2282	517468	66.2784	271.0807	49.8236	244.8060
3	4-Dec	14 : 51 : 46.272	13.2282	517395	66.2785	270.5641	47.6322	244.6166
4	5-Dec	14 : 26 : 56.707	13.2282	517473	66.2784	270.0539	45.4403	244.6662
5	6-Dec	4 : 19 : 50.165	13.2282	517455	66.2784	269.7516	44.1504	119.0818
6	6-Dec	14 : 1 : 51.034	13.2283	517488	66.2784	269.5415	43.2490	243.8344

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 126. Error of Propagated Ephemeris for #19024

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.757	234	23.58458
→3	0.321	596	47.16958
→4	0.572	889	70.75582
→5	0.413	1065	84.63733
→6	0.756	1179	94.33757
Obs 2→3	0.441	297	23.58500
→4	0.412	591	47.17123
→5	0.486	769	61.05275
→6	0.465	882	70.75299
Obs 3→4	0.209	295	23.58623
→5	0.192	473	37.46775
→6	0.350	587	47.16799
Obs 4→5	0.067	175	13.88152
→6	0.147	293	23.58176
Obs 5→6	0.115	120	9.70024

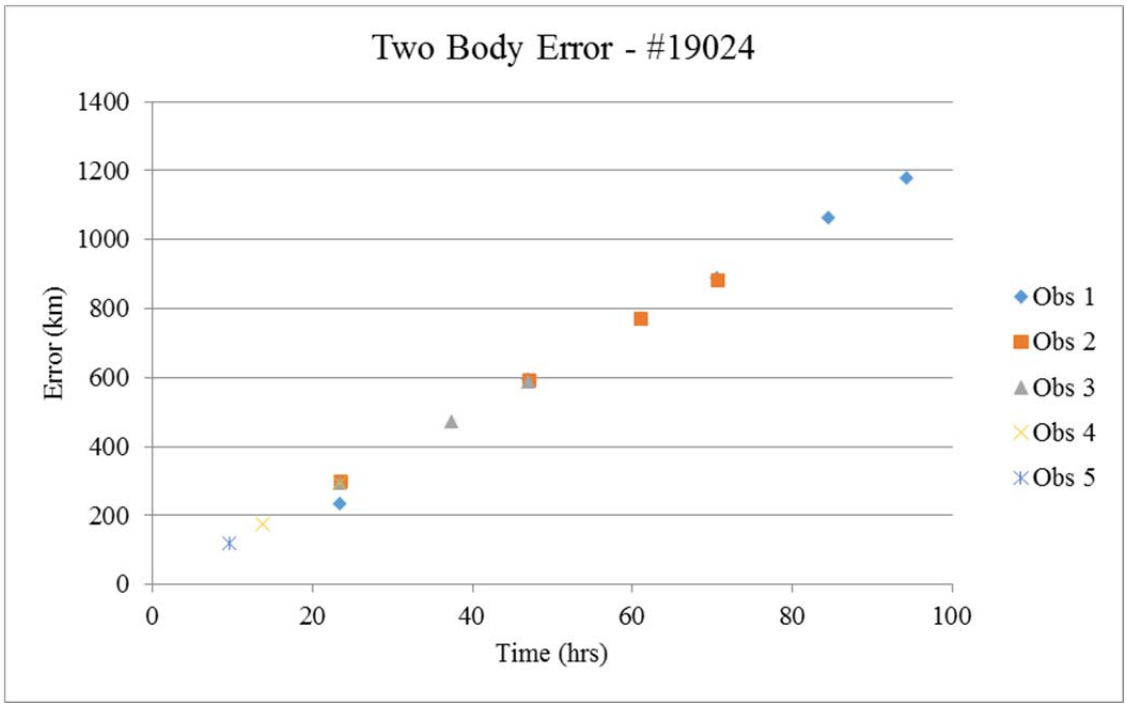

Figure 83. Error of the Two-Body Propagator Over Time–#19024

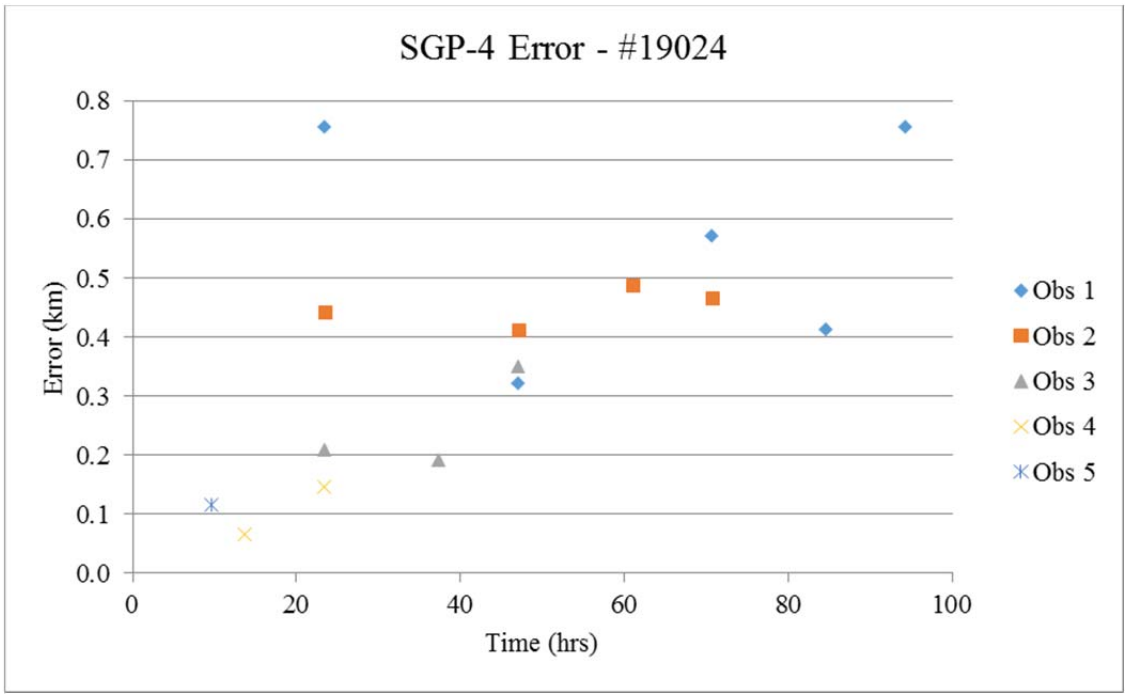

Figure 84. Error of the SGP-4 Propagator Over Time–#19024

QQ. CATALOG NUMBER 19112–COSMOS 886 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.09-0.10 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 127. Two-Line Element for #19112 30NOV–7DEC15

Obs	TLE
1	1 19112U 76126BZ 15334.81065759 +.00000249 +00000-0 +85239-4 0 9999
	2 19112 065.8257 132.0369 0944380 025.6366 338.8509 13.13857280053089
2	1 19112U 76126BZ 15335.87630747 .00000142 00000-0 59337-4 0 9993
	2 19112 65.8257 129.6259 0944456 25.1550 339.2546 13.13857360193836
3	1 19112U 76126BZ 15336.86583912 +.00000047 +00000-0 +36271-4 0 9990
	2 19112 065.8257 127.3872 0944531 024.7082 339.6289 13.13857378053350
4	1 19112U 76126BZ 15337.85537055 -.00000005 +00000-0 +23910-4 0 9998
	2 19112 065.8258 125.1485 0944624 024.2606 340.0037 13.13857551053481
5	1 19112U 76126BZ 15339.52996164 -.00000049 00000-0 13176-4 0 9995
	2 19112 65.8258 121.3599 0944762 23.5046 340.6362 13.13857918194310
6	1 19112U 76126BZ 15339.75831486 -.00000027 +00000-0 +18398-4 0 9992
	2 19112 065.8258 120.8433 0944787 023.4011 340.7227 13.13858113053738
7	1 19112U 76126BZ 15340.51949240 -.00000030 +00000-0 +17843-4 0 9994
	2 19112 065.8258 119.1213 0944844 023.0586 341.0090 13.13858324053839
8	1 19112U 76126BZ 15341.88961207 -.00000079 00000-0 59308-5 0 9998
	2 19112 65.8258 116.0215 0944950 22.4421 341.5241 13.13858267194628

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 128. Ephemeris Data Derived From TLEs for #19112

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	19 : 27 : 20.816	13.1386	0.0944380	65.8257	25.6366	132.0369	338.8509
2	1-Dec	21 : 1 : 52.965	13.1386	944456	65.8257	25.1550	129.6259	339.2546
3	2-Dec	20 : 46 : 48.500	13.1386	944531	65.8257	24.7082	127.3872	339.6289
4	3-Dec	20 : 31 : 44.016	13.1386	944624	65.8258	24.2606	125.1485	340.0037
5	5-Dec	12 : 43 : 8.686	13.1386	944762	65.8258	23.5046	121.3599	340.6362
6	5-Dec	18 : 11 : 58.404	13.1386	944787	65.8258	23.4011	120.8433	340.7227
7	6-Dec	12 : 28 : 4.143	13.1386	944844	65.8258	23.0586	119.1213	341.0090
8	7-Dec	21 : 21 : 2.483	13.1386	944950	65.8258	22.4421	116.0215	341.5241

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 129. Error of Propagated Ephemeris for #19112

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.378	321	25.57560
→3	0.865	618	49.32436
→4	1.593	916	73.07311
→5	3.301	1415	113.26330
→6	3.583	1485	118.74377
→7	4.608	1709	137.01204
→8	7.155	2115	169.89491
Obs 2→3	0.118	298	23.74876
→4	0.347	595	47.49751
→5	0.951	1096	87.68770
→6	1.057	1166	93.16818
→7	1.452	1391	111.43644
→8	2.697	1798	144.31931
Obs 3→4	0.124	298	23.74875
→5	0.314	800	63.93894
→6	0.347	869	69.41942
→7	0.409	1095	87.68768
→8	0.457	1504	120.57055
Obs 4→5	0.331	503	40.19019
→6	0.399	572	45.67066
→7	0.573	799	63.93892
→8	0.637	1208	96.82180
Obs 5→6	0.077	69	5.48048
→7	0.246	297	23.74874
→8	0.376	707	56.63161
Obs 6→7	0.1	228	18.26826
→8	0.172	639	51.15113
Obs 7→8	0.184	411	32.88287

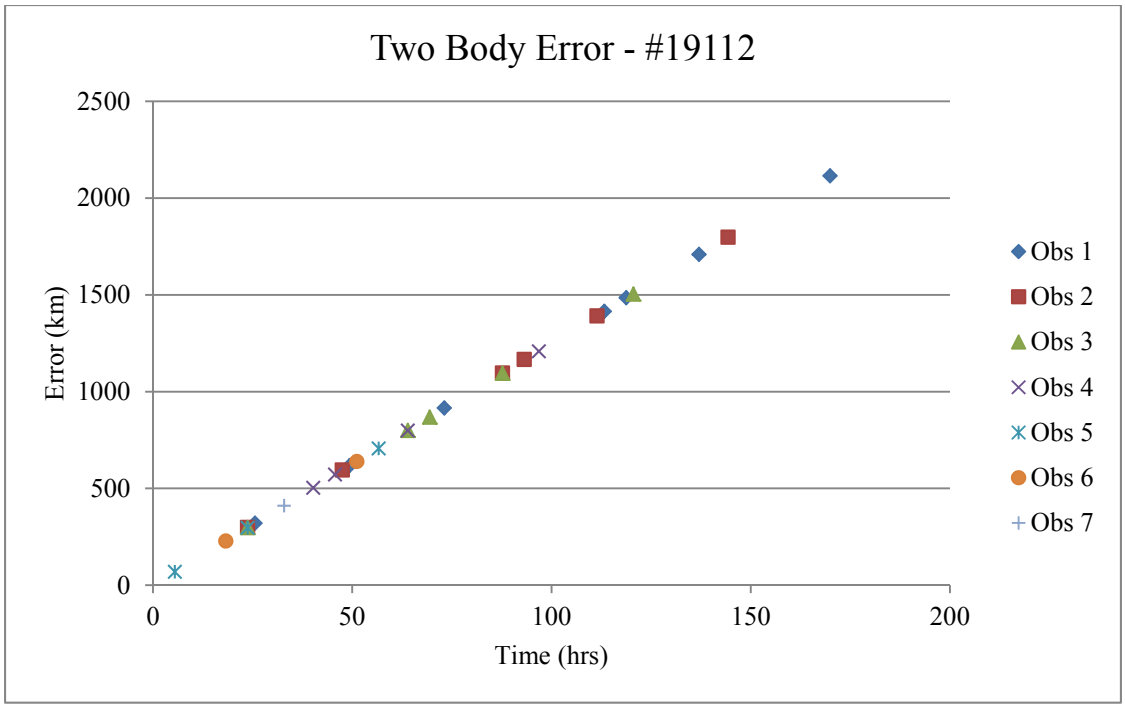

Figure 85. Error of the Two-Body Propagator Over Time–#19112

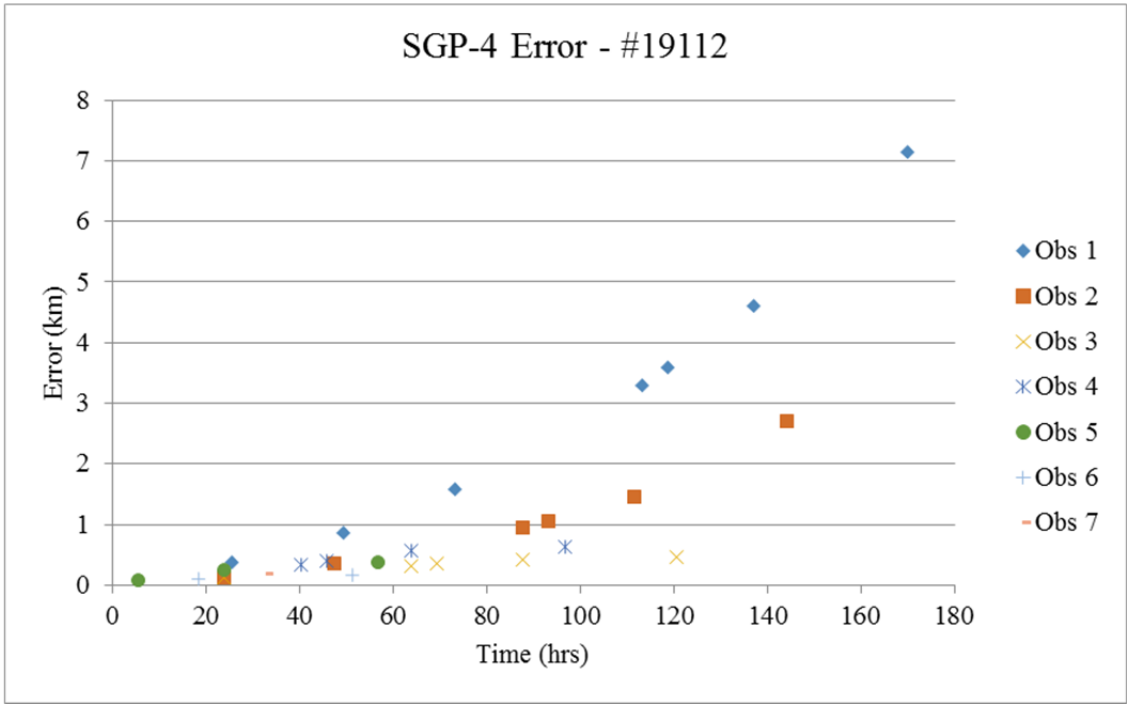

Figure 86. Error of the SGP-4 Propagator Over Time–#19112

RR. CATALOG NUMBER 19223–NOVA 2

This ephemeris data represents one of three samples for semi-major axes 7500–7600 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 130. Two-Line Element for #19223 30NOV–7DEC15

Obs	TLE
1	1 19223U 88052A 15334.79327709 +.00000068 +00000-0 +14108-3 0 9991
	2 19223 089.9704 088.9046 0031252 034.6040 119.9768 13.22615967324980
2	1 19223U 88052A 15335.07417750 .00000072 00000-0 15130-3 0 9990
	2 19223 89.9704 88.9038 0031233 33.8478 17.4427 13.22615976325295
3	1 19223U 88052A 15335.77664255 +.00000091 +00000-0 +19544-3 0 9995
	2 19223 089.9705 088.9019 0031176 031.9463 122.1373 13.22616058325111
4	1 19223U 88052A 15336.83692120 +.00000091 +00000-0 +19671-3 0 9996
	2 19223 089.9705 088.8990 0031090 029.0953 130.4964 13.22616153325254
5	1 19223U 88052A 15337.26918338 .00000079 00000-0 16658-3 0 9994
	2 19223 89.9705 88.8978 0031049 27.9372 28.6446 13.22616168325581
6	1 19223U 88052A 15337.82261859 +.00000065 +00000-0 +13511-3 0 9995
	2 19223 089.9706 088.8963 0031008 026.4609 143.7332 13.22616263325385
7	1 19223U 88052A 15338.87069251 +.00000040 +00000-0 +75629-4 0 9995
	2 19223 089.9707 088.8934 0030923 023.6222 094.0040 13.22616433325528
8	1 19223U 88052A 15339.38952941 .00000034 00000-0 61167-4 0 9994
	2 19223 89.9708 88.8920 0030881 22.2414 44.3551 13.22616481325860
9	1 19223U 88052A 15339.85319336 +.00000034 +00000-0 +60332-4 0 9994
	2 19223 089.9708 088.8907 0030842 020.9666 092.0502 13.22616501325652
10	1 19223U 88052A 15340.91425830 +.00000057 +00000-0 +11629-3 0 9999
	2 19223 089.9710 088.8878 0030751 018.0981 104.1694 13.22616598325797
11	1 19223U 88052A 15341.89672980 .00000070 00000-0 14518-3 0 9992
	2 19223 89.9710 88.8852 0030668 15.4283 102.0908 13.22616664326196

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 131. Ephemeris Data Derived From TLEs for #19223

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	19 : 2 : 19.141	13.2262	0.0031252	89.9704	34.6040	88.9046	119.9768
2	1-Dec	1 : 46 : 48.936	13.2262	31233	89.9704	33.8478	88.9038	17.4427
3	1-Dec	18 : 38 : 21.916	13.2262	31176	89.9705	31.9463	88.9019	122.1373
4	2-Dec	20 : 5 : 9.992	13.2262	31090	89.9705	29.0953	88.8990	130.4964
5	3-Dec	6 : 27 : 37.444	13.2262	31049	89.9705	27.9372	88.8978	28.6446
6	3-Dec	19 : 44 : 34.246	13.2262	31008	89.9706	26.4609	88.8963	143.7332
7	4-Dec	20 : 53 : 47.833	13.2262	30923	89.9707	23.6222	88.8934	94.0040
8	5-Dec	9 : 20 : 55.341	13.2262	30881	89.9708	22.2414	88.8920	44.3551
9	5-Dec	20 : 28 : 35.906	13.2262	30842	89.9708	20.9666	88.8907	92.0502
10	6-Dec	21 : 56 : 31.917	13.2262	30751	89.9710	18.0981	88.8878	104.1694
11	7-Dec	21 : 31 : 17.455	13.2262	30668	89.9710	15.4283	88.8852	102.0908

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 132. Error of Propagated Ephemeris for #19223

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.073	102	6.74161
→3	0.228	358	23.60077
→4	0.312	744	49.04746
→5	0.411	897	59.42175
→6	0.256	1102	72.70420
→7	0.421	1479	97.85797
→8	0.486	1662	110.31006
→9	0.628	1834	121.43799
→10	0.847	2217	146.90355
→11	1.077	2569	170.48287
Obs 2→3	0.152	256	16.85916
→4	0.236	642	42.30585
→5	0.320	795	52.68014
→6	0.205	1000	65.96259
→7	0.331	1377	91.11636
→8	0.419	1561	103.56845
→9	0.542	1732	114.69638
→10	0.775	2116	140.16194
→11	1.018	2468	163.74126
Obs 3→4	0.103	386	25.44669
→5	0.181	541	35.82098
→6	0.140	745	49.10342
→7	0.230	1123	74.25720
→8	0.372	1307	86.70928
→9	0.496	1478	97.83722
→10	0.813	1862	123.30278
→11	1.149	2216	146.88209

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.032	157	10.37429
→6	0.116	359	23.65674
→7	0.065	738	48.81051
→8	0.13	924	61.26260
→9	0.241	1094	72.39053
→10	0.532	1479	97.85609
→11	0.831	1834	121.43541
Obs 5→6	0.106	201	13.28245
→7	0.115	581	38.43622
→8	0.089	768	50.88830
→9	0.112	938	62.01624
→10	0.337	1323	87.48180
→11	0.557	1678	111.06111
Obs 6→7	0.061	381	25.15377
→8	0.051	567	37.60586
→9	0.128	737	48.73379
→10	0.343	1122	74.19935
→11	0.533	1478	97.77867
Obs 7→8	0.061	188	12.45209
→9	0.186	357	23.58002
→10	0.397	742	49.04558
→11	0.553	1099	72.62489
Obs 8→9	0.128	168	11.12793
→10	0.348	554	36.59349
→11	0.499	910	60.17281
Obs 9→10	0.22	386	25.46556
→11	0.369	742	49.04487
Obs 10→11	0.178	357	23.57932

Figure 87. Error of the Two-Body Propagator Over Time–#19223

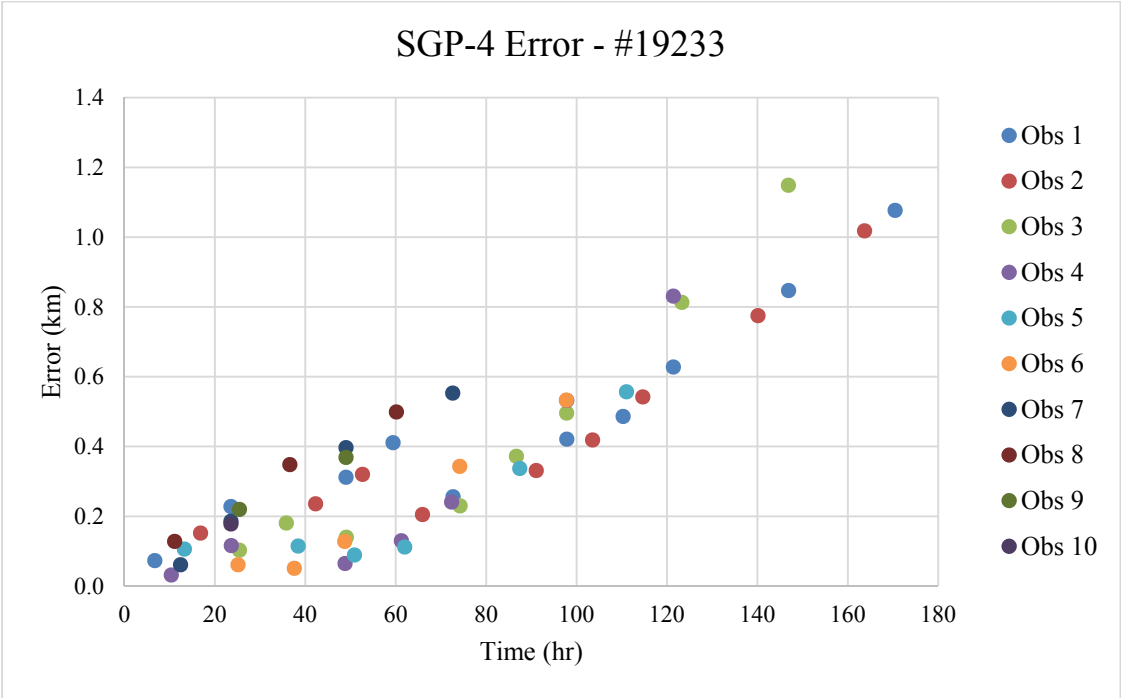

Figure 88. Error of the SGP-4 Propagator Over Time–#19223

SS. CATALOG NUMBER 19420–OSCAR 31

This ephemeris data represents one of three samples for semi-major axes 7400–7500 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 133. Two-Line Element for #19420 30NOV–7DEC15

Obs	TLE
1	1 19420U 88074B 15334.64082376 +.00000074 +00000-0 +11384-3 0 9996
	2 19420 089.9781 020.0320 0092866 251.4774 264.8858 13.42130986334837
2	1 19420U 88074B 15335.88507933 .00000066 00000-0 99839-4 0 9997
	2 19420 89.9779 20.0291 0092919 247.8693 156.7800 13.42131116335270
3	1 19420U 88074B 15336.72485775 +.00000054 +00000-0 +79441-4 0 9994
	2 19420 089.9778 020.0272 0092957 245.4349 254.3537 13.42131192335111
4	1 19420U 88074B 15337.69596905 +.00000053 +00000-0 +77121-4 0 9991
	2 19420 089.9777 020.0249 0093004 242.6172 266.4933 13.42131250335244
5	1 19420U 88074B 15338.05049133 .00000055 00000-0 80647-4 0 9997
	2 19420 89.9777 20.0241 0093022 241.5904 179.4445 13.42131280335566
6	1 19420U 88074B 15339.84798640 +.00000064 +00000-0 +95324-4 0 9997
	2 19420 089.9775 020.0199 0093116 236.3796 224.4379 13.42131519335530
7	1 19420U 88074B 15340.13623001 .00000067 00000-0 10134-3 0 9997
	2 19420 89.9775 20.0192 0093134 235.5451 177.1492 13.42131562335844
8	1 19420U 88074B 15341.03306640 +.00000081 +00000-0 +12518-3 0 9998
	2 19420 089.9774 020.0171 0093187 232.9534 190.4039 13.42131711335695

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 134. Ephemeris Data Derived From TLEs for #19420

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	15 : 22 : 47.173	13.4213	0.0092866	89.9781	251.4774	20.0320	264.8858
2	1-Dec	21 : 14 : 30.854	13.4213	92919	89.9779	247.8693	20.0291	156.7800
3	2-Dec	17 : 23 : 47.710	13.4213	92957	89.9778	245.4349	20.0272	254.3537
4	3-Dec	16 : 42 : 11.726	13.4213	93004	89.9777	242.6172	20.0249	266.4933
5	4-Dec	1 : 12 : 42.451	13.4213	93022	89.9777	241.5904	20.0241	179.4445
6	5-Dec	20 : 21 : 6.025	13.4213	93116	89.9775	236.3796	20.0199	224.4379
7	6-Dec	3 : 16 : 10.273	13.4213	93134	89.9775	235.5451	20.0192	177.1492
8	7-Dec	0 : 47 : 36.937	13.4213	93187	89.9774	232.9534	20.0171	190.4039

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 135. Error of Propagated Ephemeris for #19420

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.131	467	29.86213
→3	0.237	777	50.01682
→4	0.377	1136	73.32349
→5	0.538	1278	81.83202
→6	0.929	1944	124.97190
→7	0.912	2056	131.88975
→8	1.169	2388	153.41382
Obs 2→3	0.074	313	20.15468
→4	0.213	674	43.46135
→5	0.328	812	51.96989
→6	0.633	1481	95.10977
→7	0.622	1592	102.02762
→8	0.82	1926	123.55169
Obs 3→4	0.14	361	23.30667
→5	0.228	497	31.81521
→6	0.46	1168	74.95509
→7	0.452	1279	81.87293
→8	0.595	1613	103.39701
Obs 4→5	0.056	133	8.50853
→6	0.244	805	51.64842
→7	0.251	915	58.56626
→8	0.366	1251	80.09034
Obs 5→6	0.183	673	43.13988
→7	0.198	782	50.05773
→8	0.312	1118	71.58180
Obs 6→7	0.056	108	6.91785
→8	0.188	445	28.44192
Obs 7→8	0.134	336	21.52407

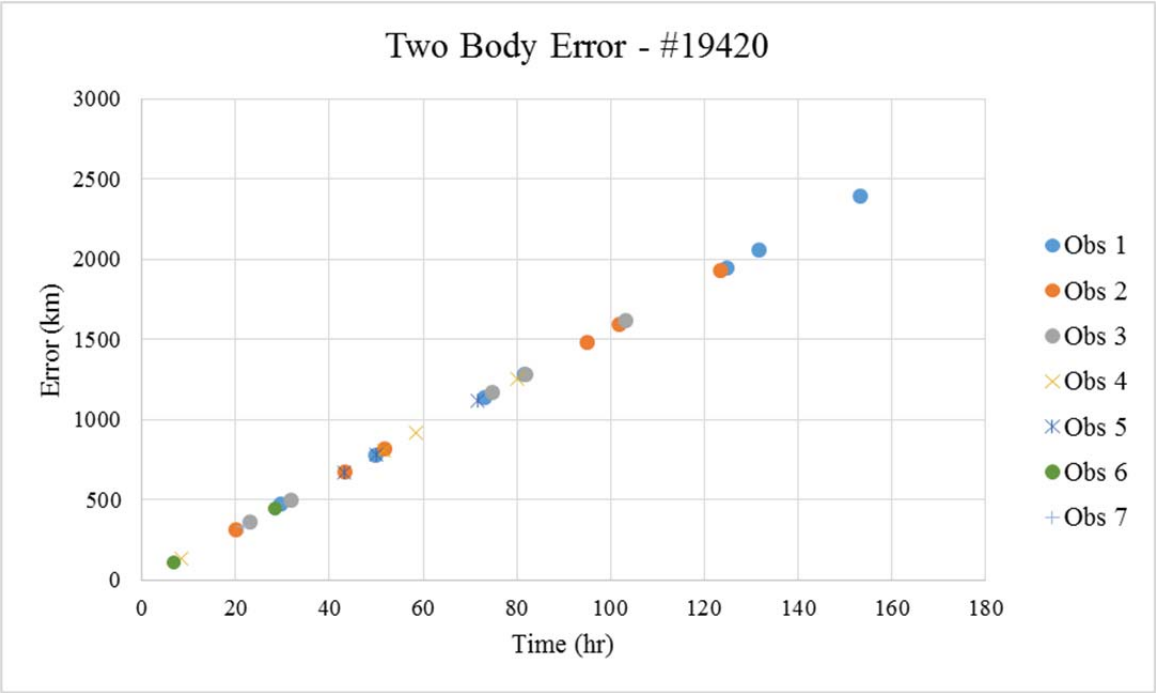

Figure 89. Error of the Two-Body Propagator Over Time–#19420

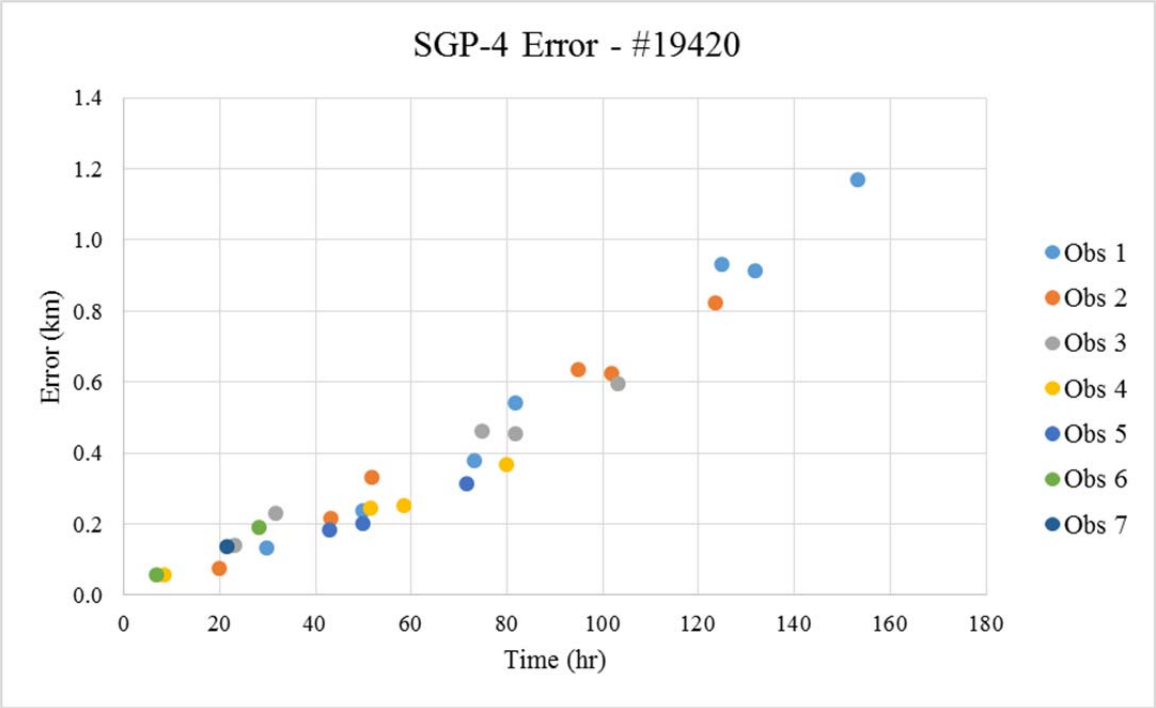

Figure 90. Error of the SGP-4 Propagator Over Time–#19420

TT. CATALOG NUMBER 19562–COSMOS 1823 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.00-0.01 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 136. Two-Line Element for #19562 30NOV–7DEC15

Obs	TLE
1	1 19562U 87020CD 15334.18853539 +.00007653 +00000-0 +15119-1 0 9997 2 19562 074.3949 241.2078 0071640 169.7595 344.1673 13.34457974711728
2	1 19562U 87020CD 15335.73711152 .00008111 00000-0 16017-1 0 9991 2 19562 74.3938 238.8627 0071280 164.4832 226.1674 13.34483212711919
3	1 19562U 87020CD 15336.71153331 +.00007890 +00000-0 +15578-1 0 9993 2 19562 074.3959 237.3882 0071204 161.1763 229.0135 13.34500162712067
4	1 19562U 87020CD 15339.71010722 .00008782 00000-0 17316-1 0 9995 2 19562 74.3985 232.8488 0071779 150.9248 239.8770 13.34547648712445
5	1 19562U 87020CD 15340.68458084 +.00009147 +00000-0 +18025-1 0 9994 2 19562 074.4002 231.3738 0072185 147.6866 243.1233 13.34564701712596

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 137. Ephemeris Data Derived From TLEs for #19562

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	4 : 31 : 29.458	13.3446	0.0071640	74.3949	169.7595	241.2078	344.1673
2	1-Dec	17 : 41 : 26.435	13.3448	71280	74.3938	164.4832	238.8627	226.1674
3	2-Dec	17 : 4 : 36.478	13.3450	71204	74.3959	161.1763	237.3882	229.0135
4	5-Dec	17 : 2 : 33.264	13.3455	71779	74.3985	150.9248	232.8488	239.8770
5	6-Dec	16 : 25 : 47.785	13.3456	72185	74.4002	147.6866	231.3738	243.1233

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 138. Error of Propagated Ephemeris for #19562

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	2.870	514	37.16583
→3	3.903	829	60.55195
→4	7.144	1739	132.51772
→5	8.087	2024	155.90509
Obs 2→3	1.684	324	23.38612
→4	8.285	1270	95.35190
→5	10.593	1564	118.73926
Obs 3→4	7.215	976	71.96577
→5	9.354	1280	95.35314
Obs 4→5	2.542	327	23.38737

Figure 91. Error of the Two-Body Propagator Over Time–#19562

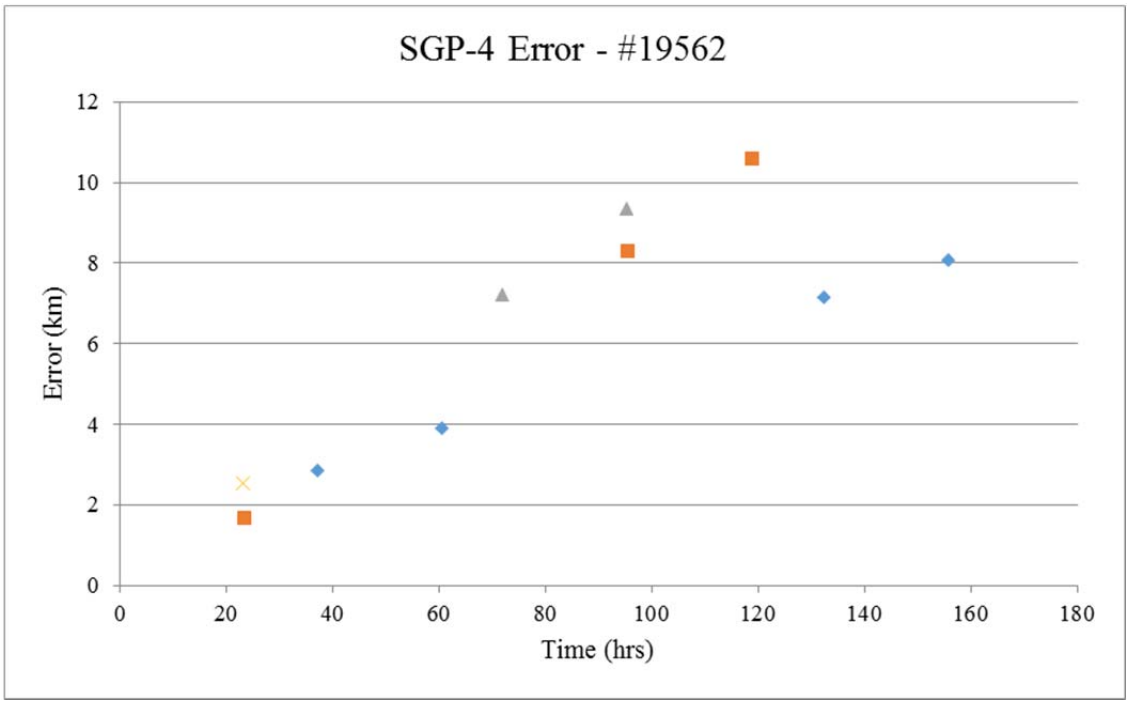

Figure 92. Error of the SGP-4 Propagator Over Time–#19562

UU. CATALOG NUMBER 20174–THOR ABLESTAR DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.04-0.05 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 139. Two-Line Element for #20174 30NOV–7DEC15

Obs	TLE
1	1 20174U 61015MK 15334.14391237 +.00000170 +00000-0 +27185-3 0 9997 2 20174 067.0629 018.7950 0497914 206.4991 185.2553 13.25863543170772
2	1 20174U 61015MK 15335.58770987 .00000130 00000-0 22551-3 0 9997 2 20174 67.0627 15.6603 0497800 205.5519 236.6346 13.25864071204711
3	1 20174U 61015MK 15337.54847375 +.00000092 +00000-0 +18203-3 0 9997 2 20174 067.0628 011.4035 0497624 204.2529 235.5587 13.25864600171228
4	1 20174U 61015MK 15339.52545544 .00000075 00000-0 16141-3 0 9990 2 20174 67.0630 7.1116 0497433 202.9333 311.9046 13.25865242205230
5	1 20174U 61015MK 15340.50595275 +.00000067 +00000-0 +15247-3 0 9993 2 20174 067.0628 004.9826 0497350 202.2810 311.9241 13.25865604171614

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 140. Ephemeris Data Derived From TLEs for #20174

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	3 : 27 : 14.029	13.2586	0.0497914	67.0629	206.4991	18.7950	185.2553
2	1-Dec	14 : 6 : 18.133	13.2586	497800	67.0627	205.5519	15.6603	236.6346
3	3-Dec	13 : 9 : 48.132	13.2586	497624	67.0628	204.2529	11.4035	235.5587
4	5-Dec	12 : 36 : 39.350	13.2587	497433	67.0630	202.9333	7.1116	311.9046
5	6-Dec	12 : 8 : 34.318	13.2587	497350	67.0628	202.2810	4.9826	311.9241

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 141. Error of Propagated Ephemeris for #20174

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hrs)
Obs 1→2	0.402	307	34.65114
→3	0.651	740	81.70947
→4	0.929	1569	129.15703
→5	1.232	1853	152.68897
Obs 2→3	0.437	428	47.05833
→4	0.437	1146	94.50589
→5	0.580	1430	118.03783
Obs 3→4	0.231	573	47.44756
→5	0.436	857	70.97950
Obs 4→5	0.214	287	23.53194

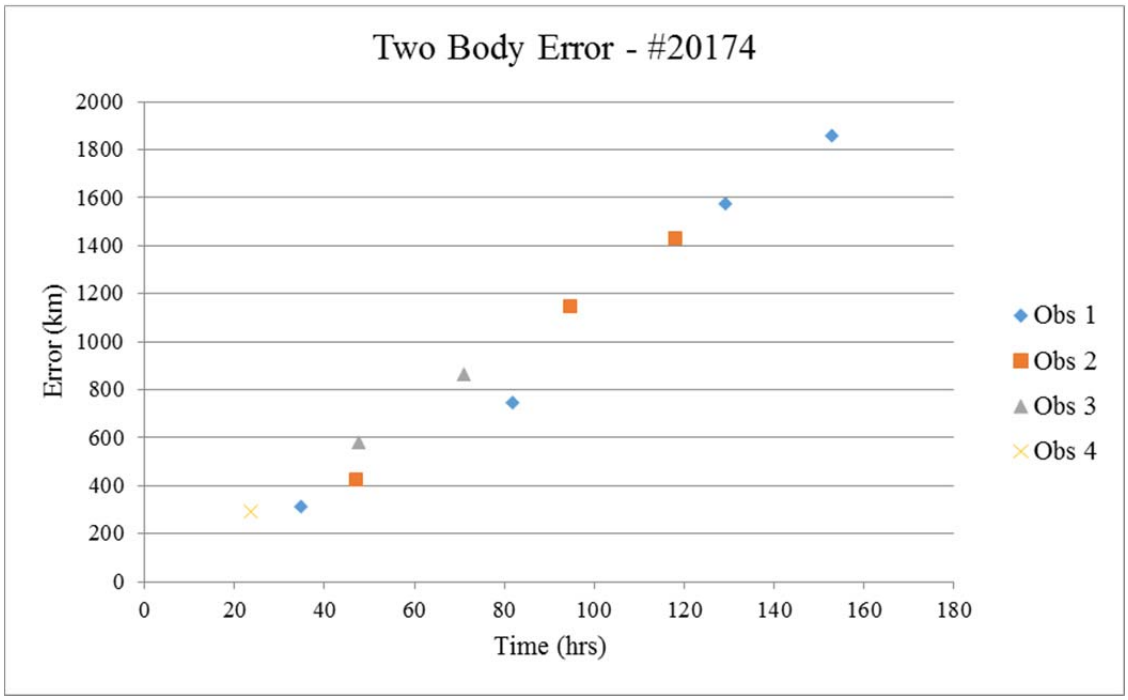

Figure 93. Error of the Two-Body Propagator Over Time–#20174

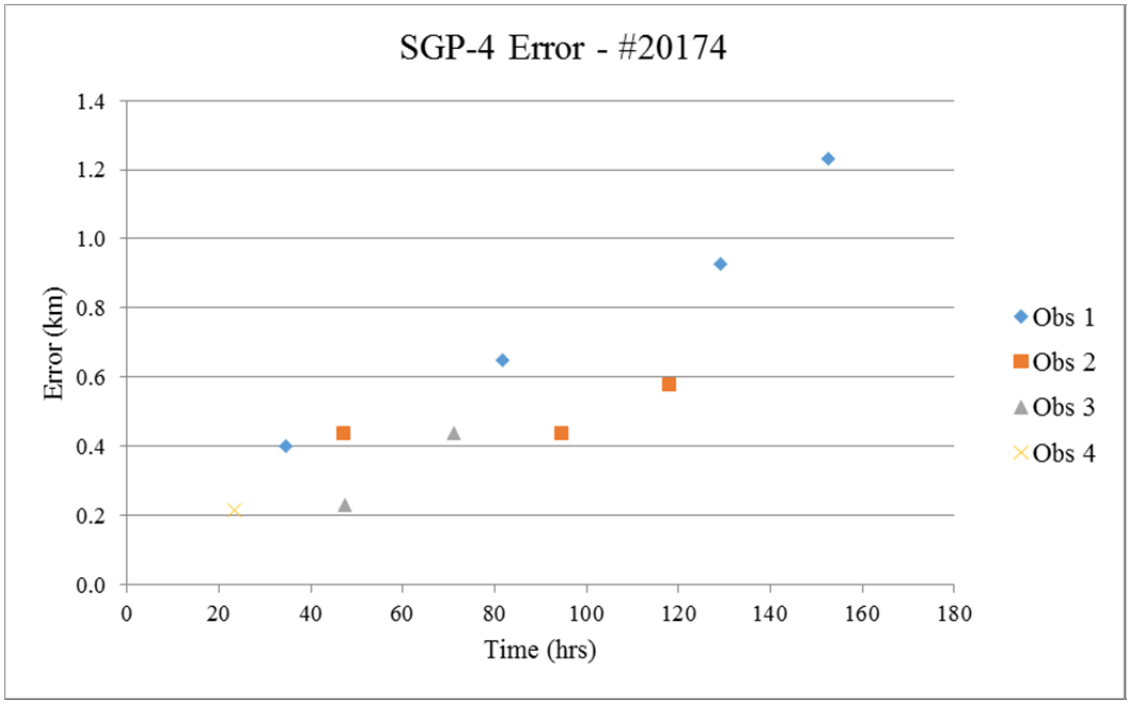

Figure 94. Error of the SGP-4 Propagator Over Time–#20174

VV. CATALOG NUMBER 20607–MACSAT 1

This ephemeris data represents one of three samples for semi-major axes 7000–7100 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 142. Two-Line Element for #20607 30NOV–7DEC15

Obs	TLE
1	1 20607U 90043A 15334.75149839 +.00000405 +00000-0 +58981-4 0 9997
	2 20607 089.7608 008.6682 0093199 299.7913 059.4061 14.71206027347735
2	1 20607U 90043A 15335.63571180 .00000357 00000-0 51733-4 0 9997
	2 20607 89.7608 8.6421 0093137 296.5887 62.5810 14.71206389368723
3	1 20607U 90043A 15336.65595825 .00000322 00000-0 46442-4 0 9995
	2 20607 89.7607 8.6119 0093071 292.8951 66.2463 14.71206892368874
4	1 20607U 90043A 15337.60818856 +.00000315 +00000-0 +45335-4 0 9995
	2 20607 089.7607 008.5837 0093024 289.4453 069.6732 14.71207452348155
5	1 20607U 90043A 15338.01628741 .00000287 00000-0 41155-4 0 9997
	2 20607 89.7606 8.5716 0093003 287.9680 71.1418 14.71207544369077
6	1 20607U 90043A 15339.10455113 .00000278 00000-0 39811-4 0 9995
	2 20607 89.7605 8.5394 0092961 284.0242 75.0655 14.71208186369239
7	1 20607U 90043A 15339.64868308 +.00000343 +00000-0 +49621-4 0 9991
	2 20607 089.7605 008.5233 0092942 282.0514 077.0301 14.71208878348459
8	1 20607U 90043A 15340.12479865 .00000341 00000-0 49334-4 0 9991
	2 20607 89.7604 8.5091 0092931 280.3256 78.7496 14.71209157369381
9	1 20607U 90043A 15341.00901336 +.00000390 +00000-0 +56811-4 0 9994
	2 20607 089.7603 008.4830 0092911 277.1220 081.9442 14.71210004348650
10	1 20607U 90043A 15341.14504639 .00000390 00000-0 56790-4 0 9990
	2 20607 89.7603 8.4789 0092909 276.6277 82.4373 14.71210109369531

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 143. Ephemeris Data Derived From TLEs for #20607

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	18 : 2 : 9.461	14.7121	0.0093199	89.7608	299.7913	8.6682	59.4061
2	1-Dec	15 : 15 : 25.500	14.7121	93137	89.7608	296.5887	8.6421	62.5810
3	2-Dec	15 : 44 : 34.793	14.7121	93071	89.7607	292.8951	8.6119	66.2463
4	3-Dec	14 : 35 : 47.492	14.7121	93024	89.7607	289.4453	8.5837	69.6732
5	4-Dec	0 : 23 : 27.232	14.7121	93003	89.7606	287.9680	8.5716	71.1418
6	5-Dec	2 : 30 : 33.218	14.7121	92961	89.7605	284.0242	8.5394	75.0655
7	5-Dec	15 : 34 : 6.218	14.7121	92942	89.7605	282.0514	8.5233	77.0301
8	6-Dec	2 : 59 : 42.603	14.7121	92931	89.7604	280.3256	8.5091	78.7496
9	7-Dec	0 : 12 : 58.754	14.7121	92911	89.7603	277.1220	8.4830	81.9442
10	7-Dec	3 : 28 : 52.008	14.7121	92909	89.7603	276.6277	8.4789	82.4373

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 144. Error of Propagated Ephemeris for #20607

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.196	383	21.22112
→3	0.454	825	45.70704
→4	0.764	1238	68.56056
→5	0.972	1415	78.35494
→6	1.469	1884	104.47327
→7	1.742	2118	117.53243
→8	1.963	2322	128.95921
→9	2.367	2699	150.18036
→10	2.442	2758	153.44515
Obs 2→3	0.127	442	24.48591
→4	0.262	855	47.33944
→5	0.359	1032	57.13381
→6	0.573	1503	83.25214
→7	0.680	1737	96.31131
→8	0.763	1942	107.73808
→9	0.881	2321	128.95924
→10	0.907	2379	132.22403
Obs 3→4	0.108	413	22.85353
→5	0.154	590	32.64790
→6	0.273	1062	58.76623
→7	0.333	1297	71.82540
→8	0.386	1502	83.25217
→9	0.494	1883	104.47332
→10	0.514	1941	107.73812

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 4→5	0.053	177	9.79437
→6	0.166	649	35.91270
→7	0.228	884	48.97187
→8	0.288	1091	60.39864
→9	0.428	1472	81.61980
→10	0.456	1531	84.88459
Obs 5→6	0.164	472	26.11833
→7	0.278	708	39.17750
→8	0.379	914	50.60427
→9	0.652	1296	71.82542
→10	0.697	1355	75.09022
Obs 6→7	0.119	236	13.05917
→8	0.212	442	24.48594
→9	0.490	825	45.70709
→10	0.538	884	48.97189
Obs 7→8	0.057	206	11.42677
→9	0.154	589	32.64793
→10	0.175	648	35.91272
Obs 8→9	0.124	383	21.22115
→10	0.147	442	24.48595
Obs 9→10	0.019	59	3.26479

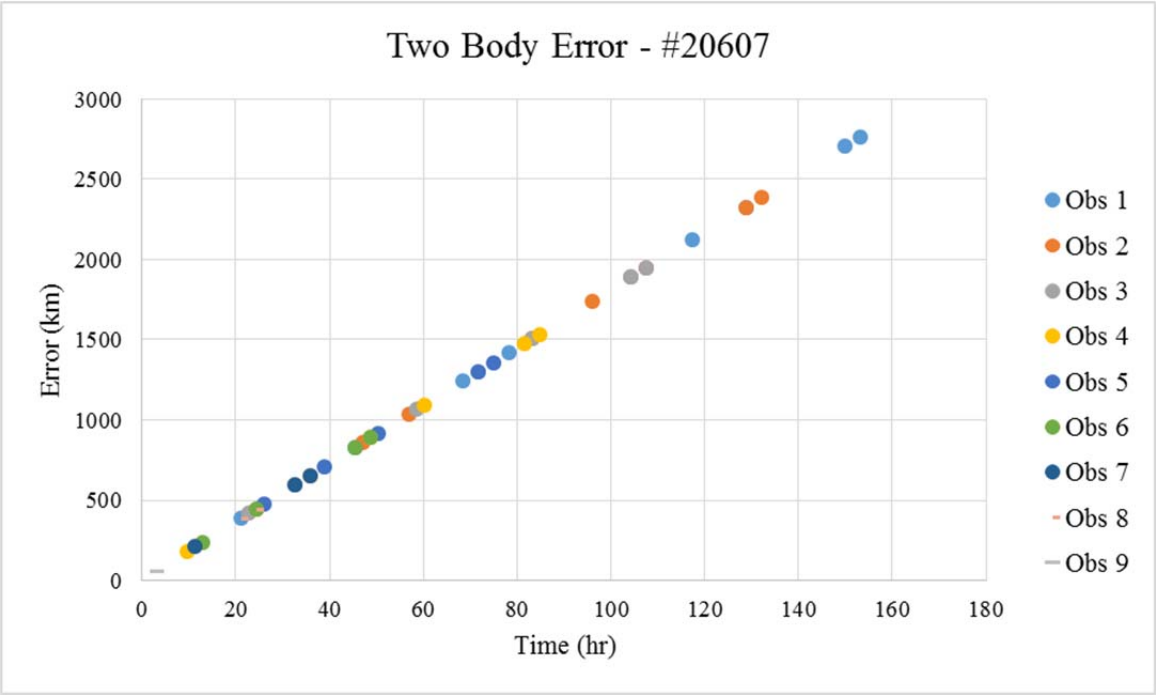

Figure 95. Error of the Two-Body Propagator Over Time–#20607

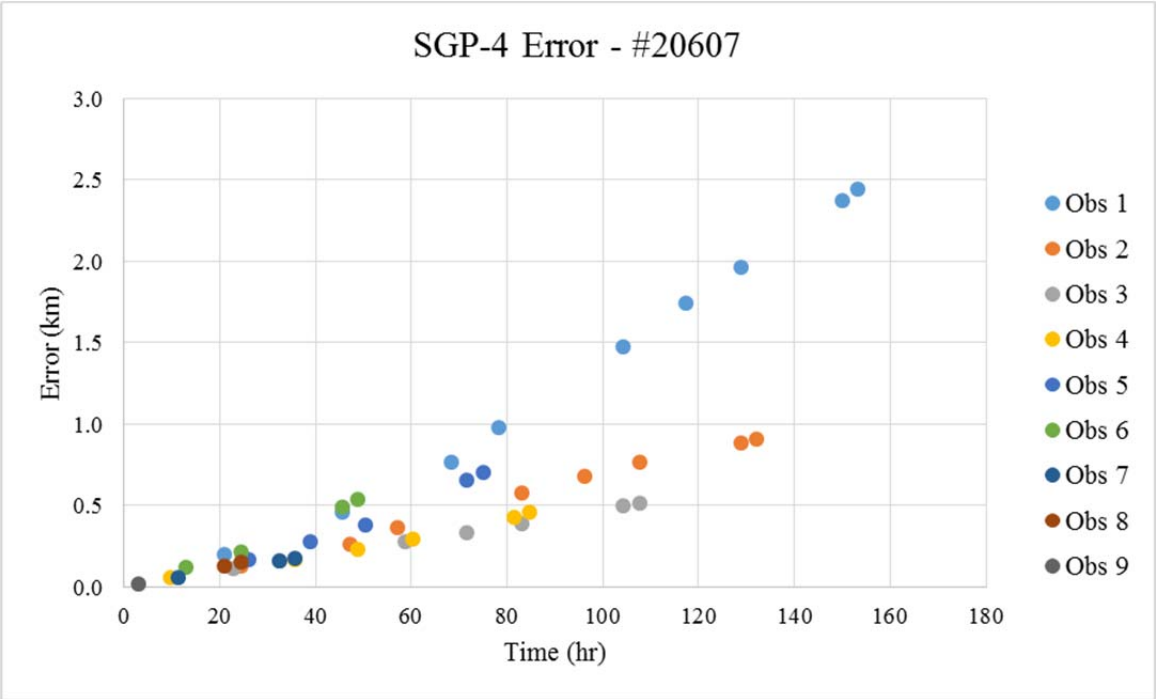

Figure 96. Error of the SGP-4 Propagator Over Time–#20607

WW. CATALOG NUMBER 20608–MACSAT 2

This ephemeris data represents one of three samples for semi-major axes 7000–7100 km in the experiment to determine the effect of the altitude on propagator accuracy and one of three samples for inclinations 80–90 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 145. Two-Line Element for #20608 30NOV–7DEC15

Obs	TLE
1	1 20608U 90043B 15334.72168198 +.00000538 +00000-0 +72868-4 0 9991
	2 20608 089.7652 008.5634 0089270 197.2048 162.6143 14.74814357370173
2	1 20608U 90043B 15335.73945211 .00000481 00000-0 64820-4 0 9998
	2 20608 89.7651 8.5337 0089434 193.5596 166.3222 14.74814960370530
3	1 20608U 90043B 15336.89292432 +.00000418 +00000-0 +55936-4 0 9994
	2 20608 089.7650 008.5000 0089612 189.4420 170.5122 14.74815683370498
4	1 20608U 90043B 15337.09647819 .00000409 00000-0 54773-4 0 9998
	2 20608 89.7649 8.4940 0089646 188.7144 171.2526 14.74815838370735
5	1 20608U 90043B 15337.84284237 +.00000383 +00000-0 +51082-4 0 9993
	2 20608 089.7649 008.4722 0089766 186.0536 173.9610 14.74816273370638
6	1 20608U 90043B 15338.86061144 .00000355 00000-0 47070-4 0 9997
	2 20608 89.7648 8.4424 0089934 182.4278 177.6520 14.74816854370991
7	1 20608U 90043B 15339.94623119 +.00000378 +00000-0 +50314-4 0 9993
	2 20608 089.7647 008.4106 0090111 178.5737 181.5759 14.74817784370948
8	1 20608U 90043B 15340.14978482 .00000374 00000-0 49685-4 0 9998
	2 20608 89.7647 8.4046 0090141 177.8510 182.3117 14.74817924371185
9	1 20608U 90043B 15340.89614796 +.00000410 +00000-0 +54708-4 0 9998
	2 20608 089.7646 008.3828 0090242 175.2077 185.0030 14.74818634371085
10	1 20608U 90043B 15341.50680858 .00000402 00000-0 53604-4 0 9994
	2 20608 89.7645 8.3649 0090340 173.0466 187.2033 14.74819001371381

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 146. Ephemeris Data Derived From TLEs for #20608

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	17 : 19 : 13.323	14.7481	0.008927	89.7652	197.2048	8.5634	162.6143
2	1-Dec	17 : 44 : 48.662	14.7481	89434	89.7651	193.5596	8.5337	166.3222
3	2-Dec	21 : 25 : 48.661	14.7482	89612	89.7650	189.4420	8.5000	170.5122
4	3-Dec	2 : 18 : 55.716	14.7482	89646	89.7649	188.7144	8.4940	171.2526
5	3-Dec	20 : 13 : 41.581	14.7482	89766	89.7649	186.0536	8.4722	173.9610
6	4-Dec	20 : 39 : 16.828	14.7482	89934	89.7648	182.4278	8.4424	177.6520
7	5-Dec	22 : 42 : 34.375	14.7482	90111	89.7647	178.5737	8.4106	181.5759
8	6-Dec	3 : 35 : 41.408	14.7482	90141	89.7647	177.8510	8.4046	182.3117
9	6-Dec	21 : 30 : 27.184	14.7482	90242	89.7646	175.2077	8.3828	185.0030
10	7-Dec	12 : 9 : 48.261	14.7482	90340	89.7645	173.0466	8.3649	187.2033

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 147. Error of Propagated Ephemeris for #20608

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.313	445	24.42648
→3	0.690	949	52.10982
→4	0.786	1037	56.99511
→5	1.222	1362	74.90785
→6	2.048	1804	99.33431
→7	2.999	2273	125.38918
→8	3.186	2361	130.27447
→9	3.971	2681	148.18718
→10	4.688	2942	162.84304
Obs 2→3	0.149	504	27.68333
→4	0.191	593	32.56863
→5	0.396	919	50.48137
→6	0.859	1362	74.90782
→7	1.385	1832	100.96270
→8	1.487	1920	105.84799
→9	1.930	2242	123.76070
→10	2.355	2505	138.41656
Obs 3→4	0.027	90	4.88529
→5	0.124	419	22.79803
→6	0.349	868	47.22449
→7	0.575	1344	73.27936
→8	0.615	1434	78.16465
→9	0.789	1760	96.07737
→10	0.979	2027	110.73322

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 4→5	0.096	329	17.91274
→6	0.310	778	42.33920
→7	0.518	1255	68.39407
→8	0.553	1344	73.27936
→9	0.707	1671	91.19207
→10	0.878	1938	105.84793
Obs 5→6	0.154	449	24.42646
→7	0.285	927	50.48133
→8	0.306	1016	55.36662
→9	0.385	1344	73.27933
→10	0.481	1611	87.93519
Obs 6→7	0.138	478	26.05487
→8	0.166	568	30.94016
→9	0.259	896	48.85288
→10	0.327	1164	63.50873
Obs 7→8	0.023	90	4.88529
→9	0.094	418	22.79800
→10	0.170	687	37.45386
Obs 8→9	0.072	329	17.91272
→10	0.146	597	32.56857
Obs 9→10	0.121	269	14.65585

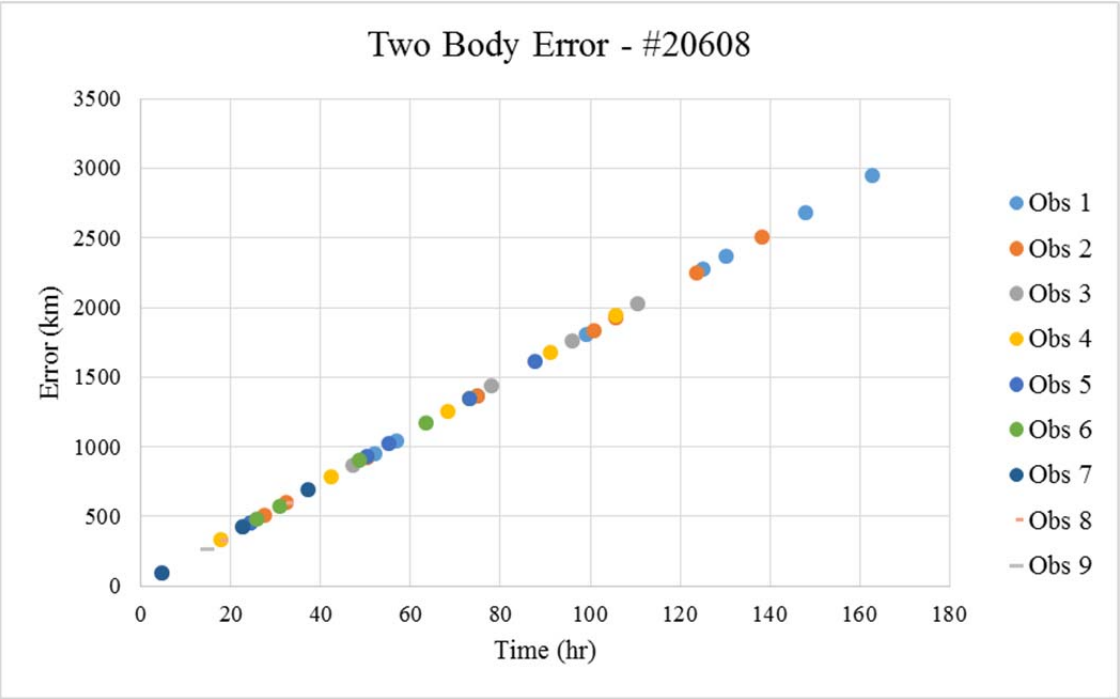

Figure 97. Error of the Two-Body Propagator Over Time–#20608

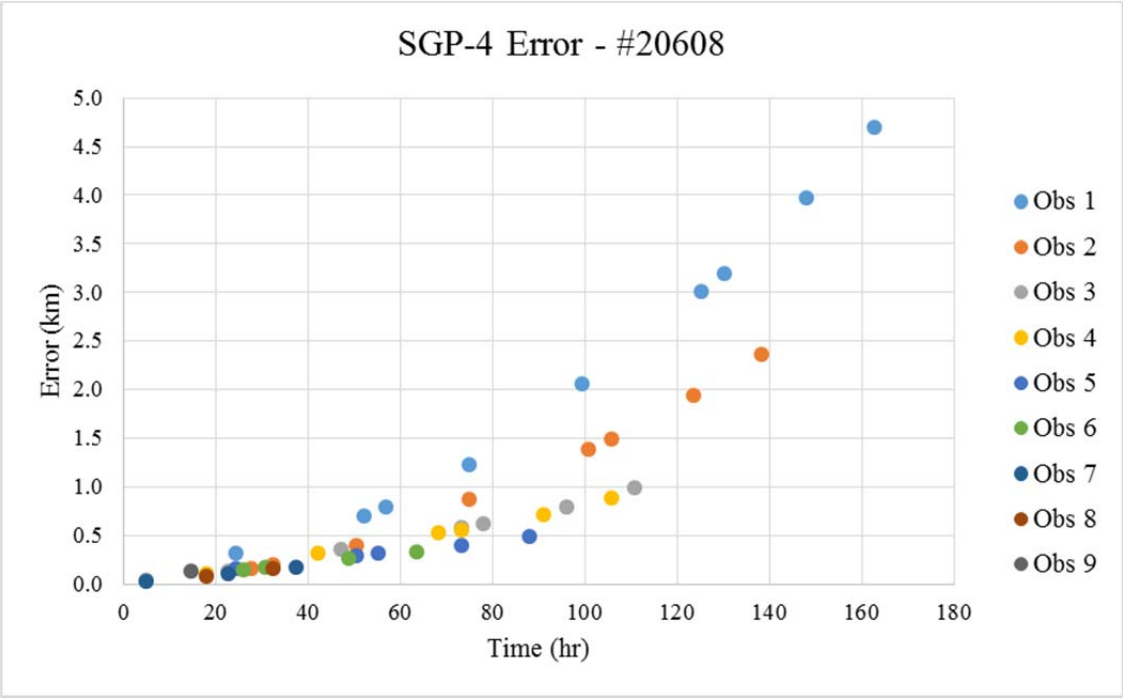

Figure 98. Error of the SGP-4 Propagator Over Time–#20608

XX. CATALOG NUMBER 21126–SL-3 DEBRIS

This ephemeris data represents one of three samples for inclinations 60–70 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 148. Two-Line Element for #21126 30NOV–7DEC15

Obs	TLE
1	1 21126U 64053C 15334.55613635 +.00000374 +00000-0 +90353-4 0 9998
	2 21126 065.0783 006.9974 0074142 305.2400 132.0115 14.64793470701321
2	1 21126U 64053C 15335.58089214 +.00000328 +00000-0 +82097-4 0 9997
	2 21126 065.0782 003.9767 0074209 304.9149 135.7294 14.64794139701474
3	1 21126U 64053C 15336.13062102 .00000327 00000-0 82003-4 0 9992
	2 21126 65.0782 2.3562 0074245 304.7385 154.5505 14.64794674722257
4	1 21126U 64053C 15336.27234182 +.00000301 +00000-0 +77298-4 0 9998
	2 21126 065.0782 001.9384 0074254 304.6919 181.8711 14.64794638701570
5	1 21126U 64053C 15337.56096245 +.00000279 +00000-0 +73434-4 0 9999
	2 21126 065.0780 358.1398 0074341 304.2857 136.9985 14.64795561701765
6	1 21126U 64053C 15338.85464758 .00000271 00000-0 71900-4 0 9998
	2 21126 65.0779 354.3261 0074426 303.8698 118.8454 14.64796571722655
7	1 21126U 64053C 15339.54102177 +.00000301 +00000-0 +77319-4 0 9993
	2 21126 065.0779 352.3028 0074485 303.6598 138.2173 14.64797246702052
8	1 21126U 64053C 15341.03360248 .00000380 00000-0 91480-4 0 9997
	2 21126 65.0778 347.9028 0074576 303.1788 88.8905 14.64798994722975

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 149. Ephemeris Data Derived From TLEs for #21126

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	13 : 20 : 50.181	14.6479	0.0074142	65.0783	305.2400	6.9974	132.0115
2	1-Dec	13 : 56 : 29.081	14.6479	74209	65.0782	304.9149	3.9767	135.7294
3	2-Dec	3 : 8 : 5.656	14.6479	74245	65.0782	304.7385	2.3562	154.5505
4	2-Dec	6 : 32 : 10.333	14.6479	74254	65.0782	304.6919	1.9384	181.8711
5	3-Dec	13 : 27 : 47.156	14.6480	74341	65.0780	304.2857	358.1398	136.9985
6	4-Dec	20 : 30 : 41.551	14.6480	74426	65.0779	303.8698	354.3261	118.8454
7	5-Dec	12 : 59 : 4.281	14.6480	74485	65.0779	303.6598	352.3028	138.2173
8	7-Dec	0 : 48 : 23.254	14.6480	74576	65.0778	303.1788	347.9028	88.8905

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 150. Error of Propagated Ephemeris for #21126

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.025	215	24.59414
→3	0.055	329	37.78763
→4	0.193	482	41.18893
→5	0.338	629	72.11583
→6	0.876	1089	103.16427
→7	1.037	1015	119.63725
→8	2.262	2198	155.45919
Obs 2→3	0.117	115	13.19349
→4	0.099	194	16.59479
→5	0.084	415	47.52169
→6	0.254	832	78.57013
→7	0.107	808	95.04311
→8	0.929	1855	130.86505
Obs 3→4	0.036	40	3.40130
→5	0.072	300	34.32819
→6	0.280	694	65.37664
→7	0.252	697	81.84962
→8	0.950	1670	117.67156
Obs 4→5	0.081	270	30.92690
→6	0.219	658	61.97534
→7	0.152	668	78.44832
→8	0.682	1623	114.27026
Obs 5→6	0.201	335	31.04844
→7	0.260	413	47.52142
→8	0.664	1195	83.34336
Obs 6→7	0.075	144	16.47298
→8	0.505	752	52.29492
Obs 7→8	0.346	515	35.82194

Figure 99. Error of the Two-Body Propagator Over Time–#21126

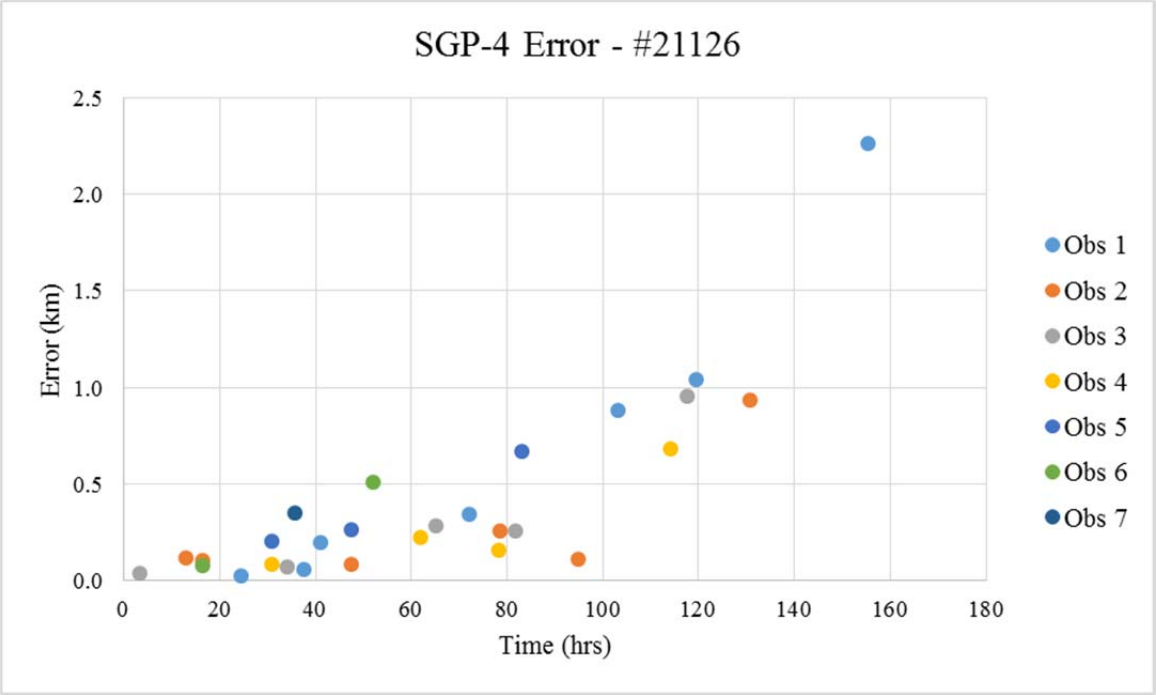

Figure 100. Error of the SGP-4 Propagator Over Time–#21126

YY. CATALOG NUMBER 22161–FREJA

This ephemeris data represents one of three samples for eccentricities 0.07-0.08 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 151. Two-Line Element for #22161 30NOV–7DEC15

Obs	TLE
1	1 22161U 92064A 15335.77523697 .00000087 00000-0 89753-4 0 9997 2 22161 63.0028 69.6986 0733179 267.1613 267.3365 13.30193452121516
2	1 22161U 92064A 15336.75181113 +.00000062 +00000-0 +78201-4 0 9998 2 22161 063.0029 067.1951 0733192 267.2504 263.8448 13.30193719121617
3	1 22161U 92064A 15337.10306537 .00000061 00000-0 77602-4 0 9990 2 22161 63.0030 66.2946 0733200 267.2826 145.8917 13.30193856121689
4	1 22161U 92064A 15337.72843859 +.00000055 +00000-0 +74828-4 0 9991 2 22161 063.0030 064.6915 0733202 267.3394 260.6090 13.30194011121749
5	1 22161U 92064A 15339.20048409 .00000038 00000-0 67090-4 0 9998 2 22161 63.0031 60.9178 0733224 267.4742 109.7766 13.30194350121965
6	1 22161U 92064A 15339.68177042 +.00000064 +00000-0 +78771-4 0 9993 2 22161 063.0031 059.6840 0733221 267.5178 254.5084 13.30194632122008
7	1 22161U 92064A 15340.49243921 .00000065 00000-0 79618-4 0 9996 2 22161 63.0031 57.6057 0733233 267.5917 176.5515 13.30194938122135
8	1 22161U 92064A 15340.93466556 +.00000072 +00000-0 +82631-4 0 9993 2 22161 063.0031 056.4720 0733239 267.6325 134.2374 13.30195163122178
9	1 22161U 92064A 15341.54689377 .00000069 00000-0 81243-4 0 9993 2 22161 63.0031 54.9024 0733247 267.6880 186.0111 13.30195383122272

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 152. Ephemeris Data Derived From TLEs for #22161

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	18 : 36 : 20.474	13.3019	0.0733179	63.0028	267.1613	69.6986	267.3365
2	2-Dec	18 : 2 : 36.482	13.3019	733192	63.0029	267.2504	67.1951	263.8448
3	3-Dec	2 : 28 : 24.848	13.3019	733200	63.0030	267.2826	66.2946	145.8917
4	3-Dec	17 : 28 : 57.094	13.3019	733202	63.0030	267.3394	64.6915	260.6090
5	5-Dec	4 : 48 : 41.825	13.3019	733224	63.0031	267.4742	60.9178	109.7766
6	5-Dec	16 : 21 : 44.964	13.3019	733221	63.0031	267.5178	59.6840	254.5084
7	6-Dec	11 : 49 : 6.748	13.3019	733233	63.0031	267.5917	57.6057	176.5515
8	6-Dec	22 : 25 : 55.104	13.3020	733239	63.0031	267.6325	56.4720	134.2374
9	7-Dec	13 : 7 : 31.622	13.3020	733247	63.0031	267.6880	54.9024	186.0111

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 153. Error of Propagated Ephemeris for #22161

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.132	314	23.43778
→3	0.247	307	31.86788
→4	0.259	616	46.87684
→5	0.470	1091	82.20593
→6	0.559	1198	93.75680
→7	0.372	727	113.21285
→8	0.586	1383	123.82629
→9	0.472	867	138.51976
Obs 2→3	0.088	81	8.43010
→4	0.126	308	23.43906
→5	0.335	780	58.76815
→6	0.380	899	70.31902
→7	0.538	577	89.77507
→8	0.657	1122	100.38851
→9	0.797	720	115.08198
Obs 3→4	0.084	197	15.00896
→5	0.281	668	50.33805
→6	0.340	792	61.88892
→7	0.442	523	81.34497
→8	0.566	1028	91.95840
→9	0.701	668	106.65188
Obs 4→5	0.207	469	35.32909
→6	0.259	600	46.87996
→7	0.474	426	66.33601
→8	0.592	860	76.94945
→9	0.778	574	91.64292
Obs 5→6	0.104	148	11.55087
→7	0.380	199	31.00692
→8	0.526	465	41.62036
→9	0.785	353	56.31383
Obs 6→7	0.191	125	19.45605
→8	0.321	336	30.06948
→9	0.499	280	44.76296
Obs 7→8	0.134	117	10.61343
→9	0.296	157	25.30691
Obs 8→9	0.133	95	14.69348

Figure 101. Error of the Two-Body Propagator Over Time–#22161

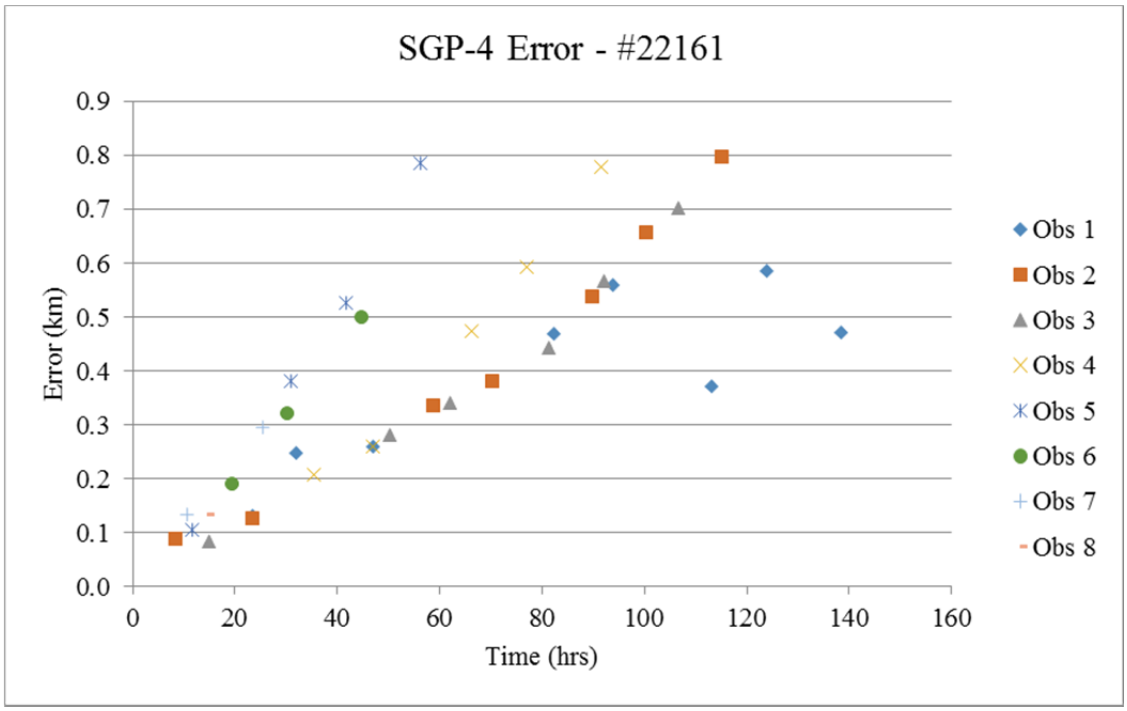

Figure 102. Error of the SGP-4 Propagator Over Time–#22161

ZZ. CATALOG NUMBER 22489–OXP-1

This ephemeris data represents one of three samples for inclinations 20–30 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 154. Two-Line Element for #22489 30NOV–7DEC15

Obs	TLE
1	1 22489U 93009A 15334.91191775 +.00000390 +00000-0 +57883-4 0 9999
	2 22489 024.9635 185.4273 0041120 136.5212 345.8919 14.44738440203401
2	1 22489U 93009A 15335.05215095 .00000367 00000-0 51532-4 0 9996
	2 22489 24.9635 184.5632 0041114 137.9976 355.2574 14.44738355203851
3	1 22489U 93009A 15335.95170152 +.00000361 +00000-0 +49734-4 0 9994
	2 22489 024.9634 179.0209 0041081 147.4658 353.9058 14.44738653203555
4	1 22489U 93009A 15336.55132676 .00000356 00000-0 48316-4 0 9999
	2 22489 24.9634 175.3264 0041058 153.7828 232.6089 14.44738830204070
5	1 22489U 93009A 15336.91790677 +.00000348 +00000-0 +46022-4 0 9993
	2 22489 024.9634 173.0677 0041045 157.6502 339.2183 14.44738938203696
6	1 22489U 93009A 15337.81053780 .00000351 00000-0 46731-4 0 9991
	2 22489 24.9633 167.5679 0041007 167.0529 301.8726 14.44739271204259
7	1 22489U 93009A 15337.95668968 +.00000337 +00000-0 +42916-4 0 9991
	2 22489 024.9634 166.6674 0040996 168.6005 342.0136 14.44739246203845
8	1 22489U 93009A 15338.85035723 .00000346 00000-0 45376-4 0 9991
	2 22489 24.9634 161.1611 0040961 178.0419 310.0322 14.44739602204403
9	1 22489U 93009A 15338.92393407 +.00000334 +00000-0 +42118-4 0 9993
	2 22489 024.9634 160.7078 0040953 178.8167 332.7122 14.44739557203984
10	1 22489U 93009A 15339.89011789 .00000364 00000-0 50339-4 0 9997
	2 22489 24.9635 154.7547 0040937 189.0478 317.8703 14.44740055204569
11	1 22489U 93009A 15340.92340348 .00000389 00000-0 57541-4 0 9998
	2 22489 24.9636 148.3883 0040915 199.9836 292.0349 14.44740593204709

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 155. Ephemeris Data Derived From TLEs for #22489

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 53 : 9.694	14.4474	0.00411	24.9635	136.521	185.427	345.892
2	1-Dec	1 : 15 : 5.842	14.4474	41114	24.9635	137.998	184.563	355.257
3	1-Dec	22 : 50 : 27.011	14.4474	41081	24.9634	147.466	179.021	353.906
4	2-Dec	13 : 13 : 54.632	14.4474	41058	24.9634	153.783	175.326	232.609
5	2-Dec	22 : 1 : 47.145	14.4474	41045	24.9634	157.65	173.068	339.218
6	3-Dec	19 : 27 : 10.466	14.4474	41007	24.9633	167.053	167.568	301.873
7	3-Dec	22 : 57 : 37.988	14.4474	40996	24.9634	168.601	166.667	342.014
8	4-Dec	20 : 24 : 30.865	14.4474	40961	24.9634	178.042	161.161	310.032
9	4-Dec	22 : 10 : 27.904	14.4474	40953	24.9634	178.817	160.708	332.712
10	5-Dec	21 : 21 : 46.186	14.4474	40937	24.9635	189.048	154.755	317.87
11	6-Dec	22 : 9 : 42.061	14.4474	40915	24.9636	199.984	148.388	292.035

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 156. Error of Propagated Ephemeris for #22489

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.056	91	3.36560
→3	0.184	681	24.95481
→4	0.34	1137	39.34582
→5	0.315	1281	48.14374
→6	0.256	1777	69.56688
→7	0.56	1973	73.07453
→8	0.551	2422	94.52255
→9	0.773	2568	96.28839
→10	0.918	3099	119.47680
→11	0.894	3620	144.27566
Obs 2→3	0.138	590	21.58921
→4	0.259	1039	35.98022
→5	0.263	1194	44.77814
→6	0.229	1692	66.20128
→7	0.487	1886	69.70893
→8	0.458	2340	91.15695
→9	0.655	2484	92.92279
→10	0.764	3019	116.11121
→11	0.744	3542	140.91006
Obs 3→4	0.108	414	14.39101
→5	0.13	625	23.18893
→6	0.175	1147	44.61207
→7	0.343	1319	48.11972
→8	0.363	1806	69.56774
→9	0.512	1935	71.33358
→10	0.635	2496	94.52199
→11	0.678	3034	119.32085

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.056	239	8.79792
→6	0.148	780	30.22106
→7	0.252	932	33.72871
→8	0.313	1443	55.17673
→9	0.422	1559	56.94258
→10	0.564	2137	80.13099
→11	0.666	2689	104.92984
Obs 5→6	0.121	554	21.42314
→7	0.191	692	24.93079
→8	0.279	1218	46.37881
→9	0.365	1324	48.14466
→10	0.523	1913	71.33307
→11	0.675	2476	96.13192
Obs 6→7	0.02	98	3.50765
→8	0.121	663	24.95567
→9	0.185	744	26.72151
→10	0.331	1357	49.90992
→11	0.468	1947	74.70878
Obs 7→8	0.131	571	21.44802
→9	0.177	647	23.21387
→10	0.354	1264	46.40228
→11	0.575	1859	71.20113
Obs 8→9	0.012	50	1.76584
→10	0.172	688	24.95426
→11	0.364	1315	49.75311
Obs 9→10	0.18	640	23.18841
→11	0.425	1269	47.98727
Obs 10→11	0.176	664	24.79885

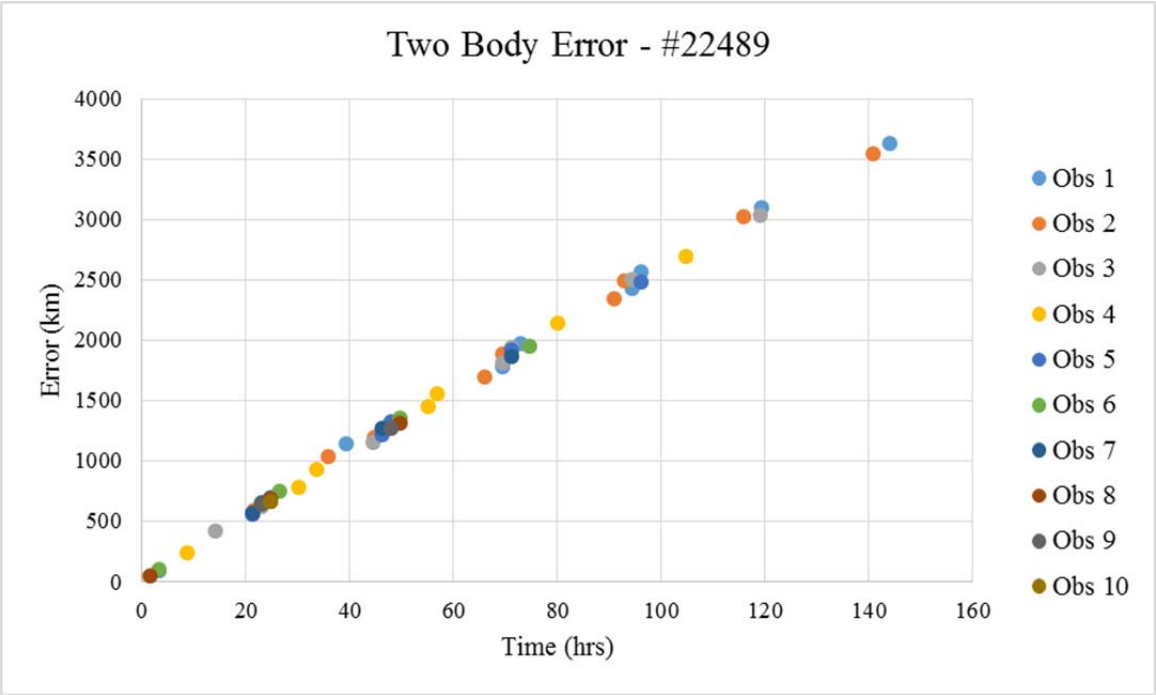

Figure 103. Error of the Two-Body Propagator Over Time–#22489

Figure 104. Error of the SGP-4 Propagator Over Time–#22489

AAA. CATALOG NUMBER 23198–APEX ROCKET BODY

This ephemeris data represents one of three samples for eccentricities 0.09-0.10 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 157. Two-Line Element for #23198 30NOV–7DEC15

Obs	TLE
1	1 23198U 94046B 15334.88105703 +.00008603 +00000-0 +44776-3 0 9992
	2 23198 069.9674 005.5432 0934918 292.9728 057.5415 13.58507423015717
2	1 23198U 94046B 15335.17556599 .00008421 00000-0 43842-3 0 9999
	2 23198 69.9674 4.9406 0934903 292.6098 57.8754 13.58512271 15729
3	1 23198U 94046B 15335.91183348 +.00008944 +00000-0 +46513-3 0 9997
	2 23198 069.9675 003.4345 0934858 291.7016 058.7123 13.58525767015853
4	1 23198U 94046B 15336.50084307 .00008468 00000-0 44069-3 0 9993
	2 23198 69.9676 2.2296 0934825 290.9751 59.3835 13.58534974 15900
5	1 23198U 94046B 15336.86897200 +.00008262 +00000-0 +43010-3 0 9993
	2 23198 069.9677 001.4765 0934808 290.5207 059.8039 13.58540890015989
6	1 23198U 94046B 15337.82610035 .00007430 00000-0 38745-3 0 9994
	2 23198 69.9679 359.5184 0934755 289.3403 60.8990 13.58555375 16082
7	1 23198U 94046B 15337.89972519 +.00006981 +00000-0 +36446-3 0 9995
	2 23198 069.9679 359.3678 0934755 289.2495 060.9833 13.58555859016127
8	1 23198U 94046B 15338.85684374 .00007433 00000-0 38750-3 0 9994
	2 23198 69.9679 357.4097 0934703 288.0684 62.0831 13.58570836 16225
9	1 23198U 94046B 15338.93046784 +.00006780 +00000-0 +35408-3 0 9991
	2 23198 069.9679 357.2591 0934704 287.9773 062.1680 13.58571000016261
10	1 23198U 94046B 15339.88757638 +.00008371 +00000-0 +43547-3 0 9994
	2 23198 069.9678 355.3009 0934639 286.7959 063.2724 13.58587581016399
11	1 23198U 94046B 15340.18206911 .00008643 00000-0 44942-3 0 9994
	2 23198 69.9677 354.6983 0934616 286.4322 63.6133 13.58592775 16408
12	1 23198U 94046B 15340.99191872 +.00010015 +00000-0 +51951-3 0 9996
	2 23198 069.9676 353.0415 0934562 285.4334 064.5512 13.58608300016540
13	1 23198U 94046B 15341.21278537 .00009656 00000-0 50115-3 0 9996
	2 23198 69.9676 352.5895 0934547 285.1610 64.8075 13.58611957 16542

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 158. Ephemeris Data Derived From TLEs for #23198

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 8 : 43.327	13.5851	0.0934918	69.9674	292.9728	5.5432	57.5415
2	1-Dec	4 : 12 : 48.902	13.5851	934903	69.9674	292.6098	4.9406	57.8754
3	1-Dec	21 : 53 : 2.413	13.5853	934858	69.9675	291.7016	3.4345	58.7123
4	2-Dec	12 : 1 : 12.841	13.5853	934825	69.9676	290.9751	2.2296	59.3835
5	2-Dec	20 : 51 : 19.181	13.5854	934808	69.9677	290.5207	1.4765	59.8039
6	3-Dec	19 : 49 : 35.070	13.5856	934755	69.9679	289.3403	359.5184	60.8990
7	3-Dec	21 : 35 : 36.256	13.5856	934755	69.9679	289.2495	359.3678	60.9833
8	4-Dec	20 : 33 : 51.299	13.5857	934703	69.9679	288.0684	357.4097	62.0831
9	4-Dec	22 : 19 : 52.421	13.5857	934704	69.9679	287.9773	357.2591	62.1680
10	5-Dec	21 : 18 : 6.599	13.5859	934639	69.9678	286.7959	355.3009	63.2724
11	6-Dec	4 : 22 : 10.771	13.5859	934616	69.9677	286.4322	354.6983	63.6133
12	6-Dec	23 : 48 : 21.777	13.5861	934562	69.9676	285.4334	353.0415	64.5512
13	7-Dec	5 : 6 : 24.656	13.5861	934547	69.9676	285.161	352.5895	64.8075

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 159. Error of Propagated Ephemeris for #23198

	SGP-4	Two Body	Time (hr)
Obs 1→2	0.153	99	7.06822
→3	0.31	347	24.73863
→4	0.581	542	38.87486
→5	0.801	664	47.70996
→6	1.815	975	70.68104
→7	1.923	999	72.44804
→8	4.291	1305	95.41888
→9	4.511	1328	97.18586
→10	8.045	1638	120.15646
→11	9.143	1730	127.22429
→12	12.14	1978	146.66068
→13	12.924	2048	151.96148
Obs 2→3	0.131	247	17.67042
→4	0.222	443	31.80665
→5	0.298	564	40.64174
→6	0.75	875	63.61282
→7	0.808	899	65.37982
→8	2.447	1205	88.35067
→9	2.606	1229	90.11764
→10	5.292	1538	113.08825
→11	6.095	1631	120.15607
→12	8.205	1879	139.59247
→13	8.728	1949	144.89327
Obs 3→4	0.416	200	14.13623
→5	0.783	323	22.97132
→6	2.402	642	45.94240
→7	2.57	666	47.70940
→8	5.871	979	70.68025
→9	6.176	1003	72.44722
→10	10.948	1318	95.41783
→11	12.486	1412	102.48566
→12	16.842	1666	121.92205
→13	18.032	1738	127.22285
Obs 4→5	0.092	124	8.83509
→6	0.654	442	31.80617
→7	0.721	466	33.57317
→8	2.49	779	56.54402
→9	2.659	803	58.31099
→10	5.479	1118	81.28160
→11	6.327	1212	88.34942
→12	8.578	1466	107.78582
→13	9.143	1539	113.08662

	SGP-4	Two Body	Time (hr)
Obs 5→6	0.31	322	22.97108
→7	0.348	346	24.73808
→8	1.626	663	47.70892
→9	1.75	687	49.47590
→10	3.897	1004	72.44651
→11	4.5	1100	79.51433
→12	5.989	1356	98.95072
→13	6.325	1429	104.25152
Obs 6→7	0.023	25	1.76700
→8	0.213	348	24.73784
→9	0.224	373	26.50482
→10	0.493	695	49.47542
→11	0.474	793	56.54325
→12	0.966	1055	75.97964
→13	1.349	1129	81.28044
Obs 7→8	0.402	323	22.97085
→9	0.452	348	24.73782
→10	1.177	670	47.70843
→11	1.683	768	54.77625
→12	3.79	1030	74.21264
→13	4.581	1104	79.51344
Obs 8→9	0.011	25	1.76698
→10	0.239	349	24.73758
→11	0.26	447	31.80541
→12	1.097	712	51.24180
→13	1.526	788	56.54260
Obs 9→10	0.608	323	22.97060
→11	1.116	422	30.03843
→12	3.313	687	49.47482
→13	4.15	762	54.77562
Obs 10→11	0.07	101	7.06783
→12	0.203	371	26.50422
→13	0.272	448	31.80502
Obs 11→12	0.175	271	19.43639
→13	0.217	348	24.73719
Obs 12→13	0.173	79	5.30080

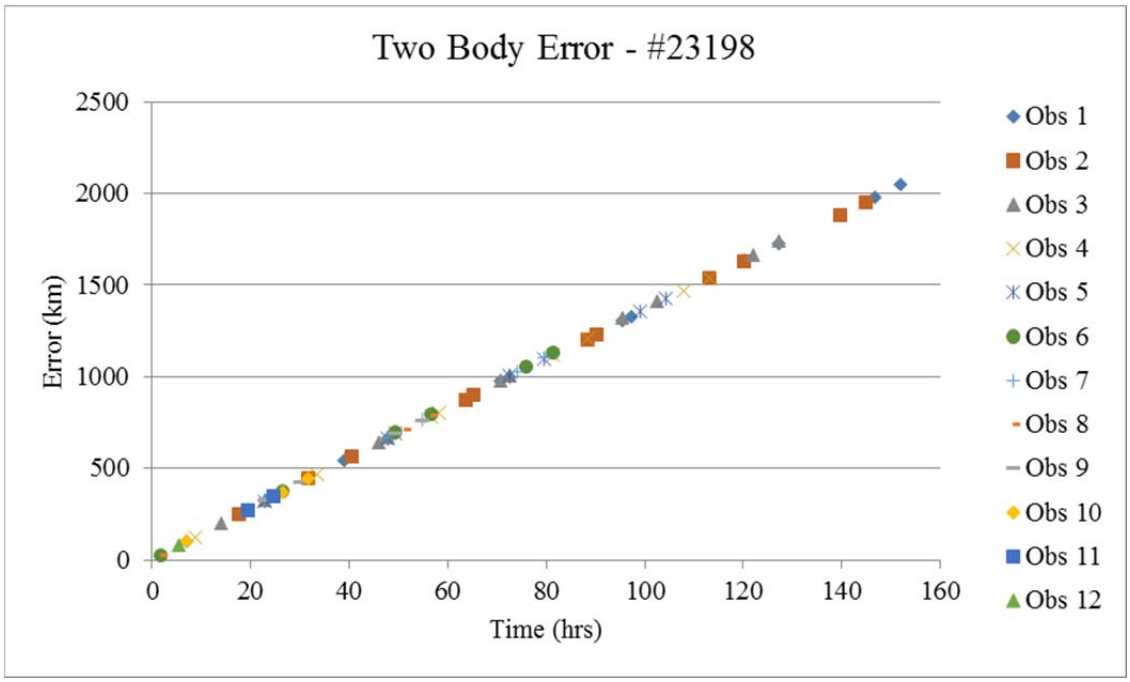

Figure 105. Error of the Two-Body Propagator Over Time–#23198

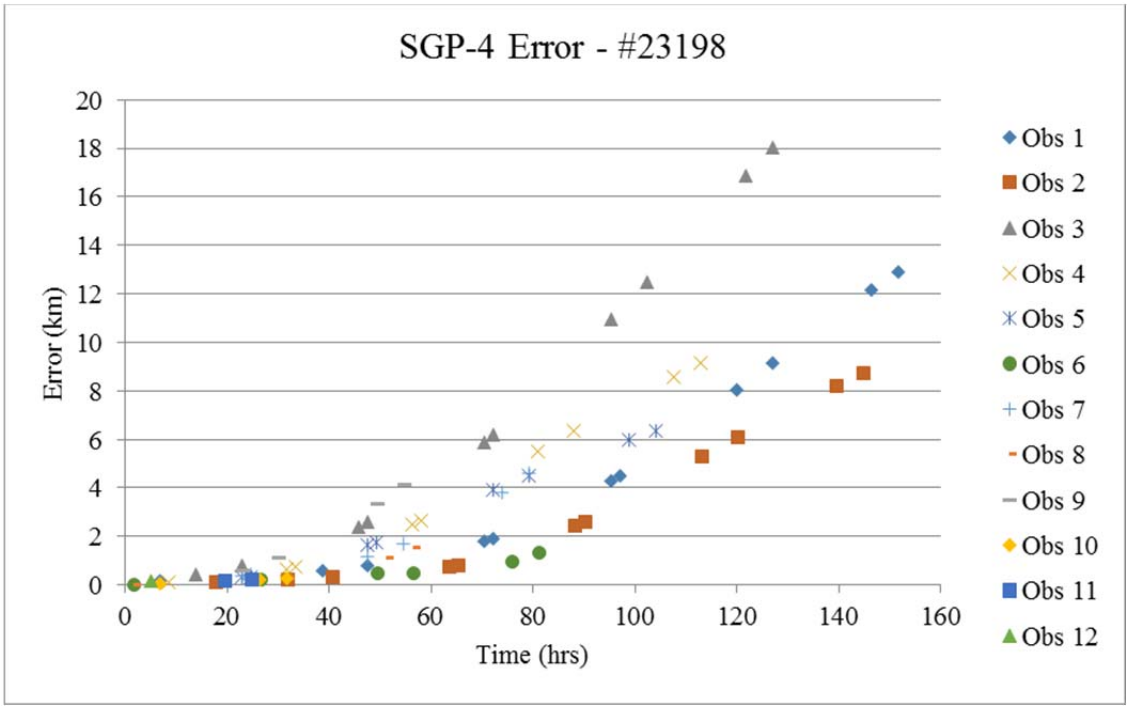

Figure 106. Error of the SGP-4 Propagator Over Time–#23198

BBB. CATALOG NUMBER 24873–IRIDIUM 921

This ephemeris data represents one of three samples for semi-major axes 6900–7000 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 160. Two-Line Element for #24873 30NOV–7DEC15

Obs	TLE
1	1 24873U 97034E 15334.93657800 +.00003491 +00000-0 +21559-3 0 9993
	2 24873 086.3940 332.3355 0005341 301.1960 081.2893 15.09553549002631
2	1 24873U 97034E 15335.55386759 .00003352 00000-0 20688-3 0 9992
	2 24873 86.3942 332.0444 0005308 298.1631 196.6498 15.09557340 3010
3	1 24873U 97034E 15335.80417234 +.00003252 +00000-0 +20065-3 0 9991
	2 24873 086.3942 331.9264 0005291 296.9809 117.1705 15.09558855002764
4	1 24873U 97034E 15336.34891138 .00003084 00000-0 19014-3 0 9995
	2 24873 86.3942 331.6696 0005261 294.3046 198.1851 15.09562019 3132
5	1 24873U 97034E 15336.79849787 +.00002783 +00000-0 +17135-3 0 9994
	2 24873 086.3942 331.4577 0005241 292.2096 121.8717 15.09563911002919
6	1 24873U 97034E 15337.06543954 .00002657 00000-0 16349-3 0 9998
	2 24873 86.3942 331.3319 0005233 290.9367 132.8398 15.09565183 3246
7	1 24873U 97034E 15337.92418943 +.00002146 +00000-0 +13165-3 0 9998
	2 24873 086.3941 330.9270 0005206 286.8518 120.5957 15.09568511003083
8	1 24873U 97034E 15338.05955612 .00002111 00000-0 12948-3 0 9992
	2 24873 86.3941 330.8632 0005202 286.2019 136.3917 15.09569142 3396
9	1 24873U 97034E 15338.92069600 +.00001934 +00000-0 +11842-3 0 9995
	2 24873 086.3939 330.4573 0005187 282.1751 137.0818 15.09572872003238
10	1 24873U 97034E 15339.52851286 .00002289 00000-0 14054-3 0 9993
	2 24873 86.3939 330.1707 0005184 279.3429 200.8414 15.09576680 3615
11	1 24873U 97034E 15339.91523638 +.00002436 +00000-0 +14966-3 0 9999
	2 24873 086.3938 329.9883 0005170 277.3748 143.0294 15.09578974003388
12	1 24873U 97034E 15340.52279192 .00002671 00000-0 16429-3 0 9998
	2 24873 86.3937 329.7019 0005166 274.5106 205.4124 15.09582358 3766
13	1 24873U 97034E 15340.96997072 +.00002979 +00000-0 +18349-3 0 9994
	2 24873 086.3935 329.4910 0005156 272.3373 116.1358 15.09585655003548
14	1 24873U 97034E 15341.51667920 .00002927 00000-0 18022-3 0 9993
	2 24873 86.3934 329.2332 0005149 269.5612 207.9931 15.09588049 3916

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 161. Ephemeris Data Derived From TLEs for #24873

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22 : 28 : 40.339	15.0955	0.0005341	86.3940	301.1960	332.3355	81.2893
2	1-Dec	13 : 17 : 34.160	15.0956	5308	86.3942	298.1631	332.0444	196.6498
3	1-Dec	19 : 18 : 0.490	15.0956	5291	86.3942	296.9809	331.9264	117.1705
4	2-Dec	8 : 22 : 25.943	15.0956	5261	86.3942	294.3046	331.6696	198.1851
5	2-Dec	19 : 9 : 50.216	15.0956	5241	86.3942	292.2096	331.4577	121.8717
6	3-Dec	1 : 34 : 13.976	15.0957	5233	86.3942	290.9367	331.3319	132.8398
7	3-Dec	22 : 10 : 49.967	15.0957	5206	86.3941	286.8518	330.9270	120.5957
8	4-Dec	1 : 25 : 45.649	15.0957	5202	86.3941	286.2019	330.8632	136.3917
9	4-Dec	22 : 5 : 48.134	15.0957	5187	86.3939	282.1751	330.4573	137.0818
10	5-Dec	12 : 41 : 3.511	15.0958	5184	86.3939	279.3429	330.1707	200.8414
11	5-Dec	21 : 57 : 56.423	15.0958	5170	86.3938	277.3748	329.9883	143.0294
12	6-Dec	12 : 32 : 49.222	15.0958	5166	86.3937	274.5106	329.7019	205.4124
13	6-Dec	23 : 16 : 45.470	15.0959	5156	86.3935	272.3373	329.4910	116.1358
14	7-Dec	12 : 24 : 1.083	15.0959	5149	86.3934	269.5612	329.2332	207.9931

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 162. Error of Propagated Ephemeris for #24873

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.264	276	14.81495
→3	0.316	387	20.82226
→4	0.383	630	33.89600
→5	0.836	823	44.68608
→6	1.189	944	51.09268
→7	2.471	1324	71.70267
→8	2.821	1381	74.95147
→9	5.180	1756	95.61883
→10	7.363	2023	110.20644
→11	8.919	2186	119.48780
→12	11.618	2448	134.06913
→13	13.388	2646	144.80143
→14	16.371	2874	157.92243
Obs 2→3	0.014	113	6.00731
→4	0.102	357	19.08105
→5	0.219	558	29.87113
→6	0.456	676	36.27773
→7	1.371	1059	56.88772
→8	1.636	1117	60.13652
→9	3.508	1497	80.80388
→10	5.310	1767	95.39149
→11	6.568	1932	104.67285
→12	8.819	2197	119.25418
→13	10.217	2398	129.98648
→14	12.708	2629	143.10748
Obs 3→4	0.123	244	13.07374
→5	0.124	445	23.86381
→6	0.313	564	30.27041
→7	1.051	947	50.88041
→8	1.278	1005	54.12921
→9	2.893	1388	74.79657
→10	4.490	1655	89.38417
→11	5.577	1821	98.66554
→12	7.570	2086	113.24687
→13	8.740	2287	123.97916
→14	10.948	2518	137.10016
Obs 4→5	0.144	201	10.79008
→6	0.266	320	17.19668
→7	0.745	703	37.80667
→8	0.907	762	41.05547
→9	2.123	1143	61.72283
→10	3.392	1412	76.31044
→11	4.208	1579	85.59180
→12	5.788	1844	100.17313
→13	6.603	2046	110.90542
→14	8.341	2278	124.02643

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 5→6	0.013	119	6.40660
→7	0.065	502	27.01660
→8	0.094	561	30.26540
→9	0.602	943	50.93276
→10	1.271	1211	65.52036
→11	1.633	1380	74.80172
→12	2.460	1644	89.38306
→13	2.648	1846	100.11535
→14	3.549	2079	113.23635
Obs 6→7	0.109	387	20.61000
→8	0.077	446	23.85880
→9	0.253	832	44.52616
→10	0.724	1103	59.11376
→11	0.937	1274	68.39512
→12	1.507	1541	82.97646
→13	1.488	1744	93.70875
→14	2.084	1980	106.82975
Obs 7→8	0.063	61	3.24880
→9	0.413	446	23.91616
→10	0.592	718	38.50376
→11	0.896	889	47.78513
→12	1.248	1156	62.36646
→13	2.047	1360	73.09875
→14	2.458	1596	86.21975
Obs 8→9	0.340	386	20.66736
→10	0.524	657	35.25496
→11	0.839	828	44.53633
→12	1.213	1096	59.11766
→13	2.033	1300	69.84995
→14	2.575	1536	82.97095
Obs 9→10	0.177	271	14.58760
→11	0.515	443	23.86897
→12	0.970	711	38.45030
→13	1.850	914	49.18259
→14	2.584	1152	62.30360
Obs 10→11	0.057	174	9.28136
→12	0.053	444	23.86270
→13	0.386	649	34.59499
→14	0.516	890	47.71599
Obs 11→12	0.239	271	14.58133
→13	0.062	474	25.31362
→14	0.145	716	38.43463
Obs 12→13	0.076	206	10.73229
→14	0.189	446	23.85329
Obs 13→14	0.497	246	13.12100

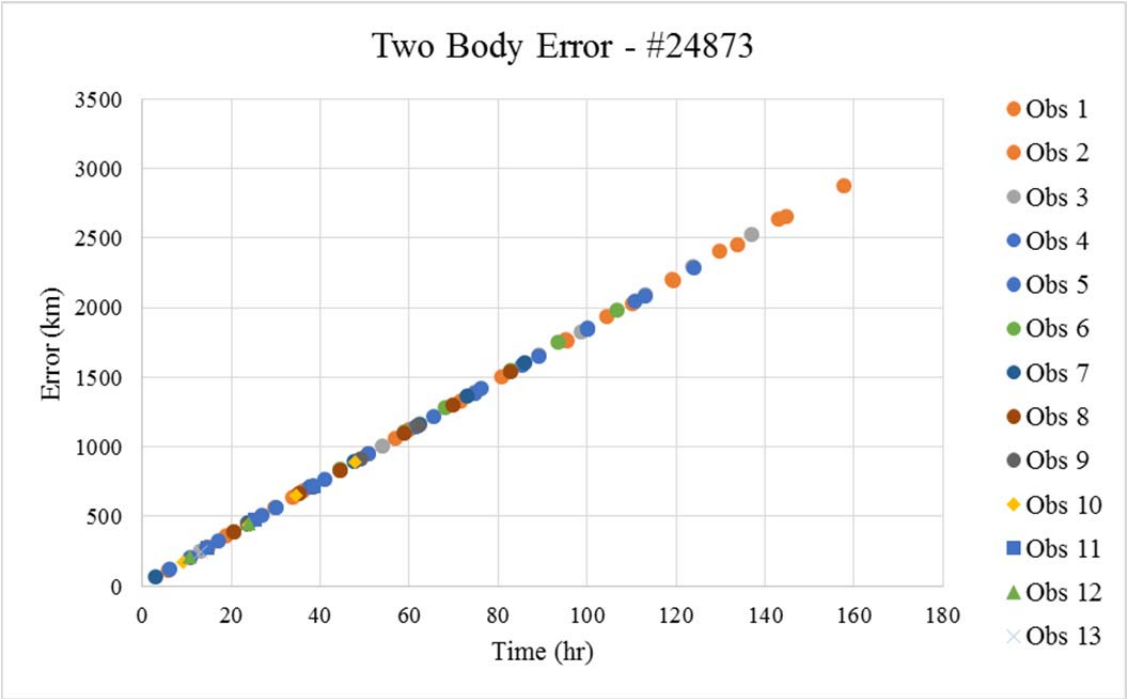

Figure 107. Error of the Two-Body Propagator Over Time–#24873

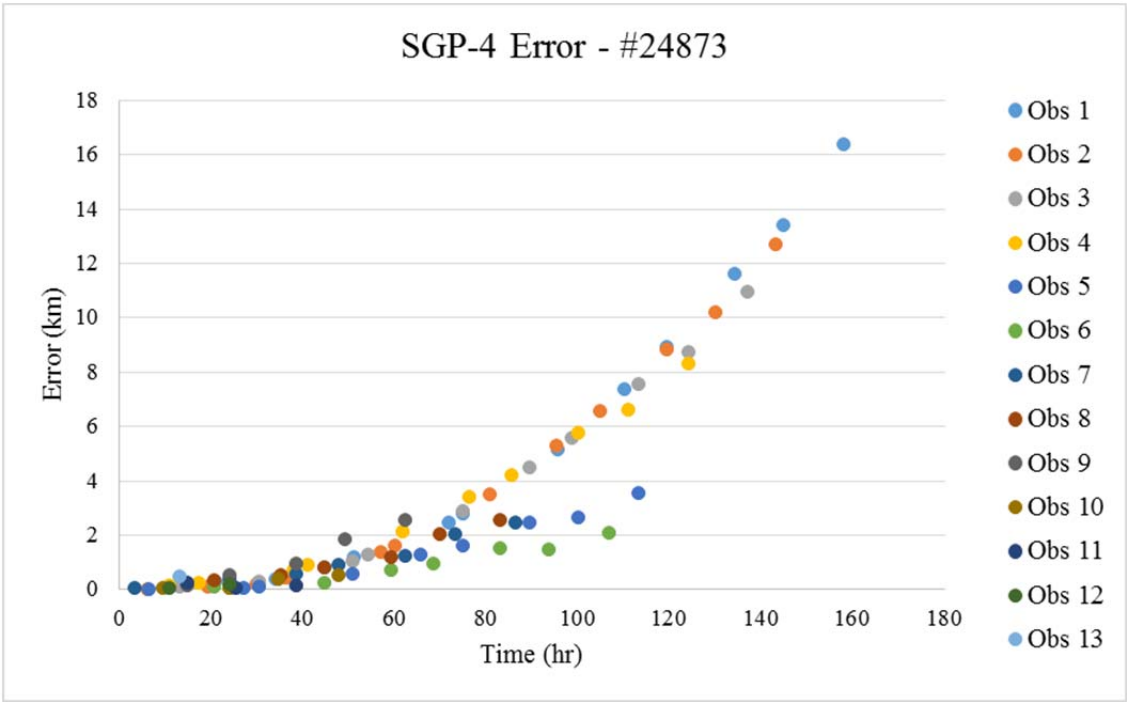

Figure 108. Error of the SGP-4 Propagator Over Time–#24873

CCC. CATALOG NUMBER 24925–DUMMY MASS 1

This ephemeris data represents one of three samples for semi-major axes 6900–7000 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 163. Two-Line Element for #24925 30NOV–7DEC15

Obs	TLE
1	1 24925U 97048A 15334.87014719 +.00000284 +00000-0 +30006-4 0 9990
	2 24925 086.3337 303.5367 0005150 223.0882 136.9940 14.85018327987619
2	1 24925U 97048A 15335.47660193 .00000257 00000-0 26888-4 0 9993
	2 24925 86.3338 303.2569 0005220 220.2796 139.8041 14.85018446987922
3	1 24925U 97048A 15335.88090499 +.00000253 +00000-0 +26408-4 0 9998
	2 24925 086.3338 303.0704 0005263 218.4254 141.6596 14.85018606987762
4	1 24925U 97048A 15336.89166258 .00000228 00000-0 23452-4 0 9995
	2 24925 86.3340 302.6042 0005386 213.8430 146.2451 14.85018855988135
5	1 24925U 97048A 15337.90242004 +.00000226 +00000-0 +23282-4 0 9991
	2 24925 086.3340 302.1379 0005512 209.4273 150.6641 14.85019199988064
6	1 24925U 97048A 15337.96980385 .00000208 00000-0 21172-4 0 9994
	2 24925 86.3340 302.1068 0005522 209.1396 150.9521 14.85019129988291
7	1 24925U 97048A 15338.91317721 +.00000204 +00000-0 +20669-4 0 9994
	2 24925 086.3341 301.6717 0005648 205.1562 154.9387 14.85019494988218
8	1 24925U 97048A 15339.04794480 .00000202 00000-0 20465-4 0 9992
	2 24925 86.3341 301.6095 0005669 204.6033 155.4921 14.85019538988452
9	1 24925U 97048A 15339.92393402 +.00000224 +00000-0 +23010-4 0 9991
	2 24925 086.3342 301.2054 0005788 201.0100 159.0886 14.85020070988365
10	1 24925U 97048A 15340.39562045 .00000230 00000-0 23657-4 0 9999
	2 24925 86.3343 300.9879 0005856 199.1463 160.9542 14.85020304988654
11	1 24925U 97048A 15340.93469053 +.00000238 +00000-0 +24672-4 0 9990
	2 24925 086.3343 300.7393 0005928 196.9750 163.1277 14.85020594988513
12	1 24925U 97048A 15341.40637689 .00000233 00000-0 24083-4 0 9996
	2 24925 86.3344 300.5217 0005997 195.1399 164.9647 14.85020733988800

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 164. Ephemeris Data Derived From TLEs for #24925

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	20 : 53 : 0.717	14.8502	0.0005150	86.3337	223.0882	303.5367	136.9940
2	1-Dec	11 : 26 : 18.407	14.8502	5220	86.3338	220.2796	303.2569	139.8041
3	1-Dec	21 : 8 : 30.191	14.8502	5263	86.3338	218.4254	303.0704	141.6596
4	2-Dec	21 : 23 : 59.647	14.8502	5386	86.3340	213.8430	302.6042	146.2451
5	3-Dec	21 : 39 : 29.091	14.8502	5512	86.3340	209.4273	302.1379	150.6641
6	3-Dec	23 : 16 : 31.053	14.8502	5522	86.3340	209.1396	302.1068	150.9521
7	4-Dec	21 : 54 : 58.511	14.8502	5648	86.3341	205.1562	301.6717	154.9387
8	5-Dec	1 : 9 : 2.431	14.8502	5669	86.3341	204.6033	301.6095	155.4921
9	5-Dec	22 : 10 : 27.899	14.8502	5788	86.3342	201.0100	301.2054	159.0886
10	6-Dec	9 : 29 : 41.607	14.8502	5856	86.3343	199.1463	300.9879	160.9542
11	6-Dec	22 : 25 : 57.262	14.8502	5928	86.3343	196.9750	300.7393	163.1277
12	7-Dec	9 : 45 : 10.963	14.8502	5997	86.3344	195.1399	300.5217	164.9647

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 165. Error of Propagated Ephemeris for #24925

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.143	267	14.55491
→3	0.193	444	24.25819
→4	0.437	888	48.51637
→5	0.824	1331	72.77455
→6	0.834	1360	74.39176
→7	1.199	1772	97.03272
→8	1.292	1798	100.26714
→9	1.609	2211	121.29088
→10	1.776	2441	132.61136
→11	2.03	2673	145.54904
→12	2.264	2875	156.86951
Obs 2→3	0.041	178	9.70327
→4	0.182	622	33.96146
→5	0.426	1065	58.21963
→6	0.429	1095	59.83685
→7	0.652	1507	82.47781
→8	0.713	1532	85.71223
→9	0.885	1948	106.73597
→10	0.966	2178	118.05644
→11	1.103	2411	130.99413
→12	1.237	2614	142.31460
Obs 3→4	0.143	444	24.25818
→5	0.372	888	48.51636
→6	0.374	917	50.13357
→7	0.581	1331	72.77453
→8	0.635	1356	76.00896
→9	0.786	1772	97.03270
→10	0.857	2002	108.35317
→11	0.975	2236	121.29085
→12	1.095	2440	132.61133
Obs 4→5	0.138	444	24.25818
→6	0.138	473	25.87539
→7	0.252	888	48.51635
→8	0.277	913	51.75077
→9	0.35	1330	72.77451
→10	0.385	1561	84.09499
→11	0.432	1796	97.03267
→12	0.486	2001	108.35314

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 5→6	0.017	30	1.61721
→7	0.108	440	24.25817
→8	0.124	467	27.49259
→9	0.215	887	48.51634
→10	0.271	1119	59.83681
→11	0.332	1355	72.77449
→12	0.379	1561	84.09496
Obs 6→7	0.101	414	22.64096
→8	0.117	440	25.87538
→9	0.242	858	46.89912
→10	0.328	1090	58.21960
→11	0.422	1325	71.15728
→12	0.487	1531	82.47775
Obs 7→8	0.024	59	3.23442
→9	0.16	443	24.25816
→10	0.253	676	35.57864
→11	0.362	912	48.51632
→12	0.426	1119	59.83679
Obs 8→9	0.138	385	21.02374
→10	0.233	617	32.34422
→11	0.346	853	45.28190
→12	0.412	1060	56.60237
Obs 9→10	0.062	233	11.32047
→11	0.138	469	24.25816
→12	0.174	676	35.57863
Obs 10→11	0.074	263	12.93768
→12	0.109	469	24.25815
Obs 11→12	0.061	233	11.32047

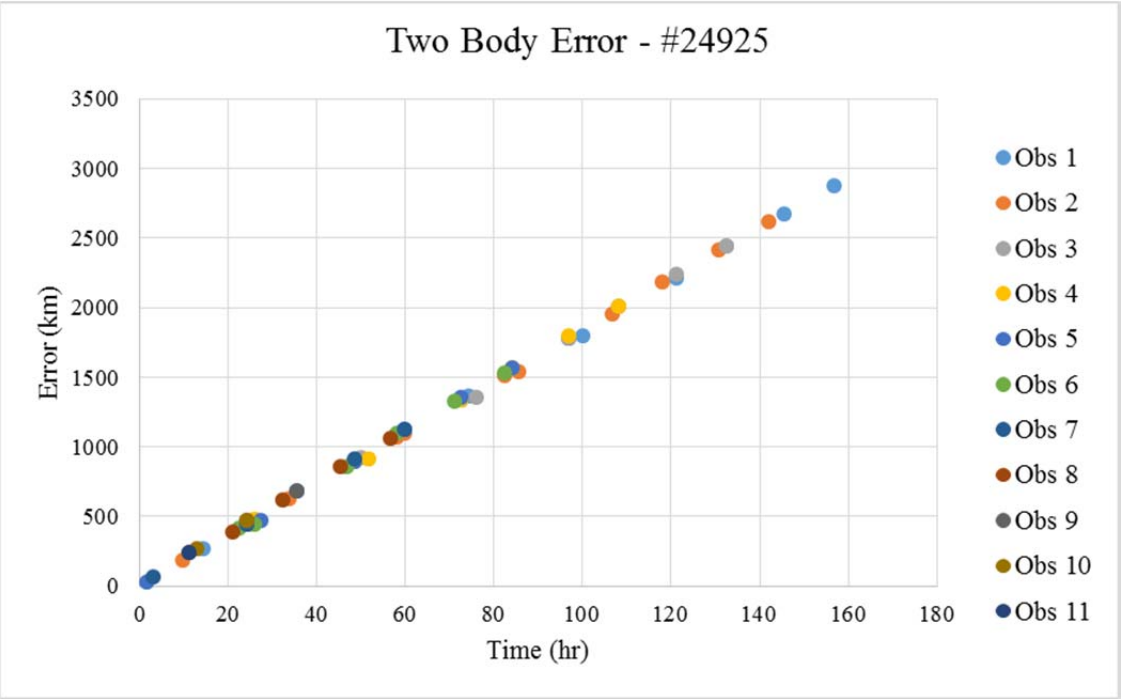

Figure 109. Error of the Two-Body Propagator Over Time–#24925

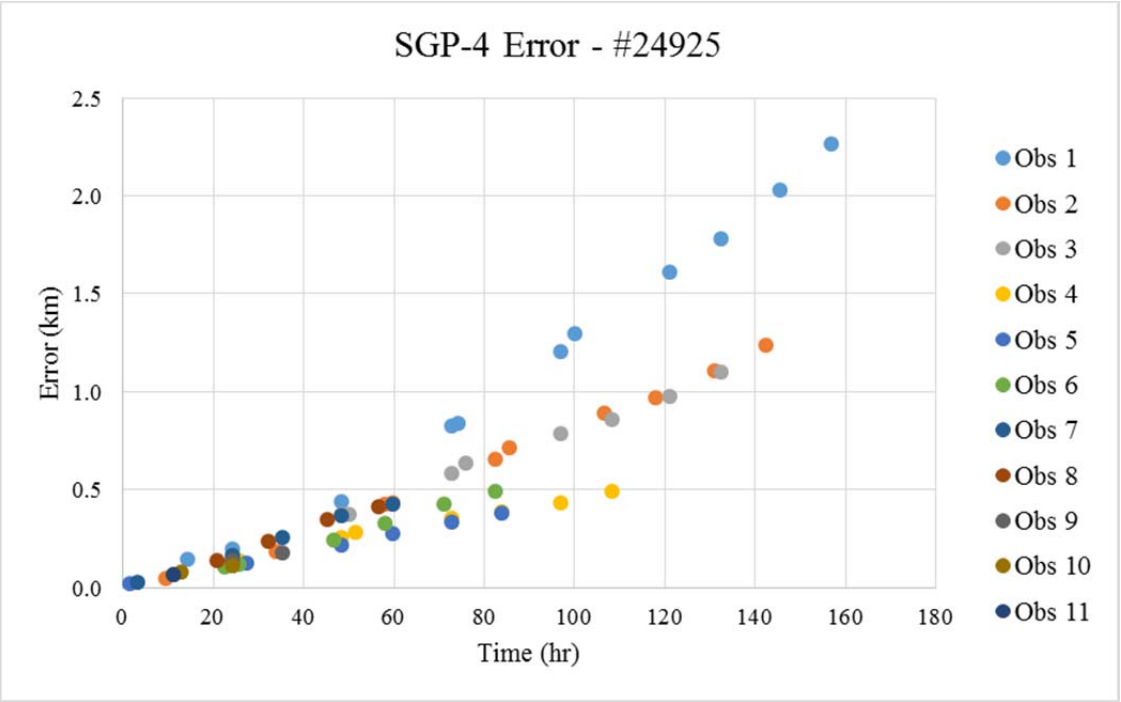

Figure 110. Error of the SGP-4 Propagator Over Time–#24925

DDD. CATALOG NUMBER 25287–IRIDIUM 64

This ephemeris data represents one of three samples for semi-major axes 7100–7200 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 166. Two-Line Element for #25287 30NOV–7DEC15

Obs	TLE
1	1 25287U 98021C 15334.93857317 +.00000275 +00000-0 +90989-4 0 9996
	2 25287 086.3966 099.8425 0001889 096.7797 263.3614 14.34210938923848
2	1 25287U 98021C 15335.49672390 .00000279 00000-0 92688-4 0 9996
	2 25287 86.3966 99.6092 0001900 97.1149 263.0263 14.34211240924201
3	1 25287U 98021C 15335.84556810 +.00000268 +00000-0 +88705-4 0 9996
	2 25287 086.3967 099.4634 0001901 097.2122 262.9290 14.34211353923971
4	1 25287U 98021C 15336.19441221 .00000268 00000-0 88734-4 0 9996
	2 25287 86.3967 99.3177 0001908 97.2785 262.8628 14.34211519924300
5	1 25287U 98021C 15336.89210032 +.00000252 +00000-0 +82807-4 0 9995
	2 25287 086.3967 099.0261 0001914 097.4927 262.6487 14.34211782924121
6	1 25287U 98021C 15337.31071307 .00000253 00000-0 83112-4 0 9994
	2 25287 86.3968 98.8512 0001920 97.6669 262.4745 14.34212008924464
7	1 25287U 98021C 15337.86886328 .00000239 00000-0 78118-4 0 9995
	2 25287 86.3969 98.6179 0001924 97.8429 262.2985 14.34212235924547
8	1 25287U 98021C 15338.84562578 +.00000255 +00000-0 +84007-4 0 9994
	2 25287 086.3970 098.2099 0001914 097.7109 262.4304 14.34212879924405
9	1 25287U 98021C 15339.19446955 .00000235 00000-0 76972-4 0 9993
	2 25287 86.3970 98.0641 0001919 97.7926 262.3487 14.34212935924738
10	1 25287U 98021C 15339.54331309 .00000270 00000-0 89457-4 0 9999
	2 25287 86.3971 97.9183 0001913 98.0304 262.1108 14.34213331924780
11	1 25287U 98021C 15339.89215665 +.00000278 +00000-0 +92319-4 0 9992
	2 25287 086.3971 097.7725 0001910 098.1757 261.9655 14.34213576924550
12	1 25287U 98021C 15340.38053760 .00000292 00000-0 97253-4 0 9992
	2 25287 86.3971 97.5685 0001911 98.2816 261.8596 14.34213927924903
13	1 25287U 98021C 15340.93868710 +.00000299 +00000-0 +99862-4 0 9997
	2 25287 086.3972 097.3351 0001907 098.4298 261.7114 14.34214271924709
14	1 25287U 98021C 15341.49683655 .00000290 00000-0 96463-4 0 9997
	2 25287 86.3972 97.1019 0001917 98.6928 261.4485 14.34214530925067

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 167. Ephemeris Data Derived From TLEs for #25287

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22 : 31 : 32.722	14.34211	0.0001889	86.397	96.7797	99.8425	263.3614
2	1-Dec	11 : 55 : 16.945	14.34211	1900	86.397	97.1149	99.6092	263.0263
3	1-Dec	20 : 17 : 37.084	14.34211	1901	86.397	97.2122	99.4634	262.9290
4	2-Dec	4 : 39 : 57.215	14.34212	1908	86.397	97.2785	99.3177	262.8628
5	2-Dec	21 : 24 : 37.468	14.34212	1914	86.397	97.4927	99.0261	262.6487
6	3-Dec	7 : 27 : 25.609	14.34212	1920	86.397	97.6669	98.8512	262.4745
7	3-Dec	20 : 51 : 9.787	14.34212	1924	86.397	97.8429	98.6179	262.2985
8	4-Dec	20 : 17 : 42.067	14.34213	1914	86.397	97.7109	98.2099	262.4304
9	5-Dec	4 : 40 : 2.169	14.34213	1919	86.397	97.7926	98.0641	262.3487
10	5-Dec	13 : 2 : 22.251	14.34213	1913	86.397	98.0304	97.9183	262.1108
11	5-Dec	21 : 24 : 42.335	14.34214	1910	86.397	98.1757	97.7725	261.9655
12	6-Dec	9 : 7 : 58.449	14.34214	1911	86.397	98.2816	97.5685	261.8596
13	6-Dec	22 : 31 : 42.565	14.34214	1907	86.397	98.4298	97.3351	261.7114
14	7-Dec	11 : 55 : 26.678	14.34215	1917	86.397	98.6928	97.1019	261.4485

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 168. Error of Propagated Ephemeris for #25287

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.052	231	13.39562
→3	0.091	375	21.76788
→4	0.124	519	30.14014
→5	0.185	807	46.88465
→6	0.224	980	56.93136
→7	0.268	1210	70.32696
→8	0.331	1611	93.76926
→9	0.362	1754	102.14151
→10	0.392	1897	110.51376
→11	0.433	2039	118.88600
→12	0.469	2238	130.60715
→13	0.545	2465	144.00273
→14	0.594	2691	157.39832
Obs 2→3	0.048	144	8.37226
→4	0.077	289	16.74452
→5	0.140	577	33.48903
→6	0.180	750	43.53574
→7	0.224	980	56.93135
→8	0.280	1382	80.37365
→9	0.319	1525	88.74590
→10	0.341	1668	97.11814
→11	0.375	1810	105.49039
→12	0.414	2010	117.21153
→13	0.476	2237	130.60712
→14	0.524	2464	144.00270
Obs 3→4	0.032	144	8.37226
→5	0.090	433	25.11677
→6	0.128	605	35.16348
→7	0.180	836	48.55908
→8	0.311	1238	72.00138
→9	0.311	1381	80.37363
→10	0.395	1524	88.74588
→11	0.468	1667	97.11813
→12	0.514	1867	108.83927
→13	0.644	2095	122.23486
→14	0.711	2322	135.63044
Obs 4→5	0.060	288	16.74451
→6	0.098	461	26.79122
→7	0.152	692	40.18683
→8	0.293	1094	63.62913
→9	0.291	1238	72.00138
→10	0.382	1381	80.37362
→11	0.458	1524	88.74587
→12	0.508	1724	100.46701
→13	0.643	1952	113.86260
→14	0.713	2180	127.25818

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 5→6	0.050	173	10.04671
→7	0.129	403	23.44231
→8	0.346	806	46.88461
→9	0.350	950	55.25686
→10	0.482	1094	63.62911
→11	0.590	1237	72.00135
→12	0.680	1437	83.72249
→13	0.872	1666	97.11808
→14	0.995	1894	110.51367
Obs 6→7	0.077	231	13.39561
→8	0.285	634	36.83791
→9	0.287	777	45.21016
→10	0.416	921	53.58240
→11	0.519	1065	61.95465
→12	0.607	1265	73.67579
→13	0.790	1494	87.07138
→14	0.908	1723	100.46696
Obs 7→8	0.233	403	23.44230
→9	0.247	547	31.81455
→10	0.389	691	40.18680
→11	0.506	835	48.55904
→12	0.620	1035	60.28018
→13	0.830	1265	73.67577
→14	0.981	1494	87.07136
Obs 8→9	0.038	144	8.37225
→10	0.102	288	16.74450
→11	0.181	432	25.11674
→12	0.254	633	36.83788
→13	0.395	863	50.23347
→14	0.486	1092	63.62906
Obs 9→10	0.127	144	8.37224
→11	0.227	288	16.74449
→12	0.331	489	28.46563
→13	0.513	719	41.86122
→14	0.648	949	55.25681
Obs 10→11	0.063	144	8.37225
→12	0.117	345	20.09339
→13	0.221	575	33.48898
→14	0.281	805	46.88456
Obs 11→12	0.049	201	11.72114
→13	0.132	431	25.11673
→14	0.181	661	38.51232
Obs 12→13	0.067	230	13.39559
→14	0.104	460	26.79117
Obs 13→14	0.053	230	13.39559

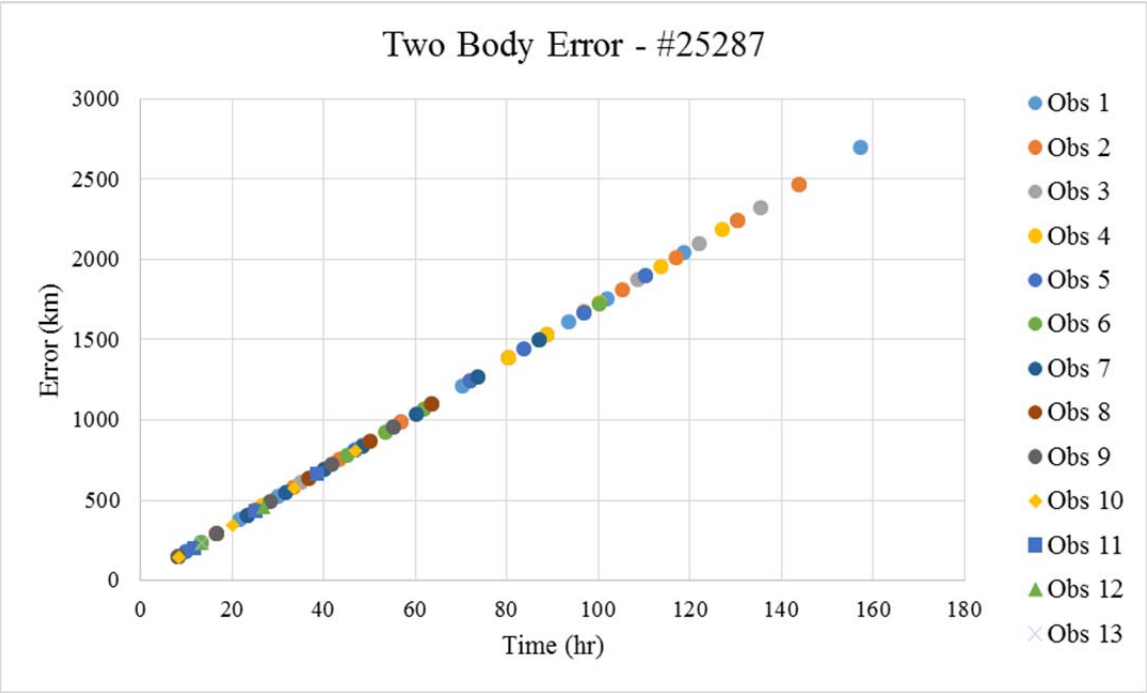

Figure 111. Error of the Two-Body Propagator Over Time–#25287

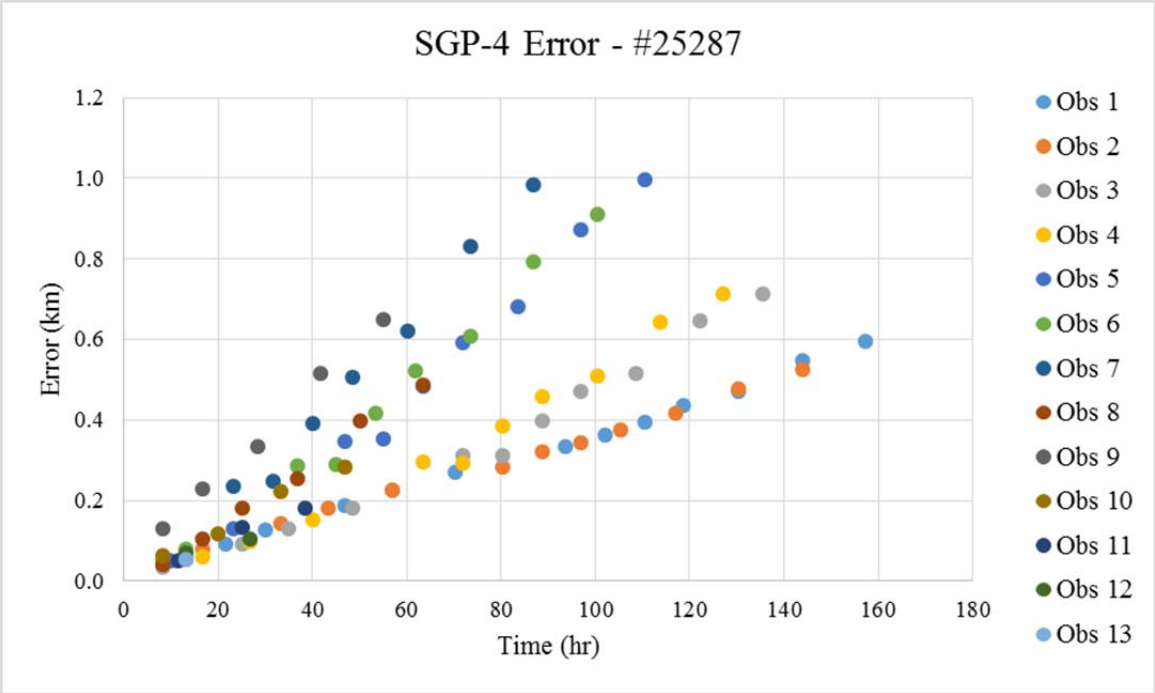

Figure 112. Error of the SGP-4 Propagator Over Time–#25287

EEE. CATALOG NUMBER 25288–IRIDIUM 65

This ephemeris data represents one of three samples for semi-major axes 7100–7200 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 169. Two-Line Element for #25288 30NOV–7DEC15

Obs	TLE
1	1 25288U 98021D 15334.87514769 +.00000277 +00000-0 +91809-4 0 9995
	2 25288 086.3964 099.7827 0002108 090.9657 269.1780 14.34210780923852
2	1 25288U 98021D 15335.57283613 .00000287 00000-0 95411-4 0 9998
	2 25288 86.3965 99.4912 0002108 91.0770 269.0667 14.34211163924235
3	1 25288U 98021D 15335.92168029 +.00000284 +00000-0 +94392-4 0 9994
	2 25288 086.3965 099.3454 0002105 090.8646 269.2791 14.34211345924008
4	1 25288U 98021D 15336.54959960 .00000279 00000-0 92664-4 0 9999
	2 25288 86.3966 99.0830 0002103 90.7107 269.4330 14.34211653924376
5	1 25288U 98021D 15336.89844365 +.00000273 +00000-0 +90561-4 0 9997
	2 25288 086.3966 098.9372 0002097 090.6714 269.4722 14.34211798924140
6	1 25288U 98021D 15337.31705641 .00000269 00000-0 89001-4 0 9990
	2 25288 86.3966 98.7623 0002097 90.7301 269.4135 14.34212010924483
7	1 25288U 98021D 15337.94497543 .00000252 00000-0 82857-4 0 9992
	2 25288 86.3967 98.4998 0002090 90.7541 269.3894 14.34212247924578
8	1 25288U 98021D 15338.92173809 +.00000235 +00000-0 +76695-4 0 9991
	2 25288 086.3968 098.0916 0002080 090.7018 269.4416 14.34212696924437
9	1 25288U 98021D 15339.20081307 .00000238 00000-0 78007-4 0 9996
	2 25288 86.3968 97.9750 0002079 90.7487 269.3947 14.34212850924754
10	1 25288U 98021D 15339.54965673 .00000260 00000-0 85620-4 0 9994
	2 25288 86.3969 97.8293 0002074 90.7336 269.4097 14.34213153924804
11	1 25288U 98021D 15339.89850035 +.00000248 +00000-0 +81394-4 0 9997
	2 25288 086.3969 097.6834 0002069 090.8372 269.3061 14.34213304924570
12	1 25288U 98021D 15340.45665002 .00000279 00000-0 92619-4 0 9995
	2 25288 86.3970 97.4502 0002067 91.1675 268.9757 14.34213742924933
13	1 25288U 98021D 15340.94503089 +.00000286 +00000-0 +95193-4 0 9993
	2 25288 086.3971 097.2461 0002063 091.0662 269.0770 14.34214056924720
14	1 25288U 98021D 15341.43341168 .00000290 00000-0 96490-4 0 9992
	2 25288 86.3971 97.0420 0002061 91.2606 268.8825 14.34214335925078

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 170. Ephemeris Data Derived From TLEs for #25288

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 0 : 12.760	14.3421	0.0002108	86.3964	90.9657	99.7827	269.1780
2	1-Dec	13 : 44 : 53.042	14.3421	2108	86.3965	91.0770	99.4912	269.0667
3	1-Dec	22 : 7 : 13.177	14.3421	2105	86.3965	90.8646	99.3454	269.2791
4	2-Dec	13 : 11 : 25.405	14.3421	2103	86.3966	90.7107	99.0830	269.4330
5	2-Dec	21 : 33 : 45.531	14.3421	2097	86.3966	90.6714	98.9372	269.4722
6	3-Dec	7 : 36 : 33.674	14.3421	2097	86.3966	90.7301	98.7623	269.4135
7	3-Dec	22 : 40 : 45.877	14.3421	2090	86.3967	90.7541	98.4998	269.3894
8	4-Dec	22 : 7 : 18.171	14.3421	2080	86.3968	90.7018	98.0916	269.4416
9	5-Dec	4 : 49 : 10.249	14.3421	2079	86.3968	90.7487	97.9750	269.3947
10	5-Dec	13 : 11 : 30.341	14.3421	2074	86.3969	90.7336	97.8293	269.4097
11	5-Dec	21 : 33 : 50.430	14.3421	2069	86.3969	90.8372	97.6834	269.3061
12	6-Dec	10 : 57 : 34.562	14.3421	2067	86.3970	91.1675	97.4502	268.9757
13	6-Dec	22 : 40 : 50.669	14.3421	2063	86.3971	91.0662	97.2461	269.0770
14	7-Dec	10 : 24 : 6.769	14.3421	2061	86.3971	91.2606	97.0420	268.8825

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 171. Error of Propagated Ephemeris for #25288

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.065	289	16.74452
→3	0.089	433	25.11678
→4	0.144	692	40.18685
→5	0.170	836	48.55910
→6	0.209	1009	58.60581
→7	0.263	1267	73.67587
→8	0.342	1668	97.11817
→9	0.367	1783	103.81597
→10	0.399	1874	112.18822
→11	0.433	2068	120.56046
→12	0.490	2295	133.95606
→13	0.537	2494	145.67720
→14	0.571	2691	157.39834
Obs 2→3	0.025	144	8.37226
→4	0.079	404	23.44232
→5	0.104	548	31.81458
→6	0.142	721	41.86129
→7	0.196	980	56.93134
→8	0.282	1382	80.37365
→9	0.309	1496	87.07145
→10	0.338	1588	95.44369
→11	0.366	1782	103.81594
→12	0.423	2010	117.21153
→13	0.459	2209	128.93267
→14	0.510	2408	140.65381
Obs 3→4	0.060	260	15.07006
→5	0.080	404	23.44232
→6	0.119	577	33.48903
→7	0.172	836	48.55908
→8	0.254	1238	72.00139
→9	0.280	1352	78.69919
→10	0.310	1444	87.07143
→11	0.340	1639	95.44368
→12	0.396	1867	108.83927
→13	0.435	2067	120.56041
→14	0.479	2265	132.28155
Obs 4→5	0.032	144	8.37226
→6	0.067	317	18.41896
→7	0.122	576	33.48902
→8	0.203	979	56.93132
→9	0.228	1094	63.62912
→10	0.259	1186	72.00137
→11	0.294	1381	80.37362
→12	0.352	1610	93.76921
→13	0.400	1809	105.49035
→14	0.438	2009	117.21149

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 5→6	0.044	172	10.04671
→7	0.104	432	25.11676
→8	0.188	835	48.55907
→9	0.214	950	55.25687
→10	0.253	1042	63.62911
→11	0.299	1237	72.00136
→12	0.367	1466	85.39695
→13	0.434	1666	97.11809
→14	0.471	1866	108.83923
Obs 6→7	0.063	259	15.07006
→8	0.151	663	38.51236
→9	0.178	777	45.21016
→10	0.219	869	53.58241
→11	0.268	1064	61.95465
→12	0.342	1294	75.35025
→13	0.417	1494	87.07139
→14	0.459	1695	98.79253
Obs 7→8	0.116	403	23.44230
→9	0.153	518	30.14010
→10	0.213	610	38.51235
→11	0.283	806	46.88460
→12	0.391	1036	60.28019
→13	0.505	1236	72.00133
→14	0.580	1437	83.72247
Obs 8→9	0.041	115	6.69780
→10	0.104	207	15.07005
→11	0.180	403	23.44229
→12	0.306	633	36.83789
→13	0.438	834	48.55903
→14	0.539	1035	60.28017
Obs 9→10	0.059	92	8.37225
→11	0.130	288	16.74449
→12	0.249	518	30.14009
→13	0.371	719	41.86123
→14	0.467	920	53.58237
Obs 10→11	0.053	196	8.37225
→12	0.136	426	21.76784
→13	0.218	627	33.48898
→14	0.278	828	45.21012
Obs 11→12	0.092	230	13.39559
→13	0.182	432	25.11673
→14	0.253	633	36.83787
Obs 12→13	0.056	201	11.72114
→14	0.100	403	23.44228
Obs 13→14	0.046	201	11.72114

Figure 113. Error of the Two-Body Propagator Over Time–#25288

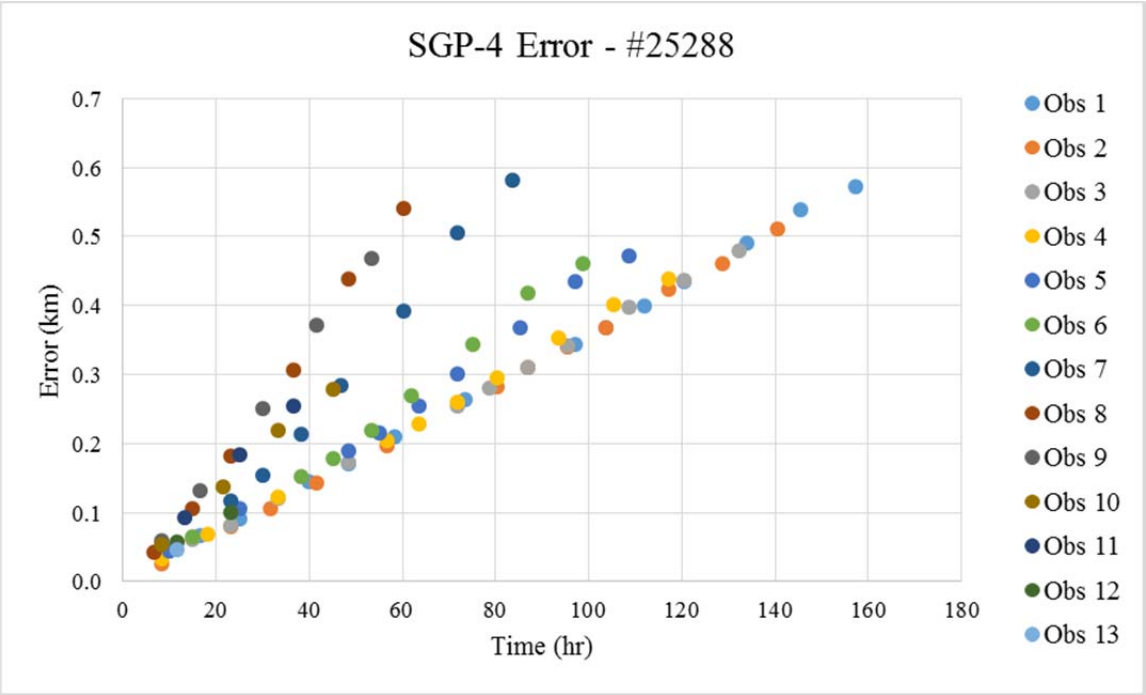

Figure 114. Error of the SGP-4 Propagator Over Time–#25288

FFF. CATALOG NUMBER 25484–PEGASUS ROCKET BODY

This ephemeris data represents one of three samples for inclinations 40–50 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 172. Two-Line Element for #25484 30NOV–7DEC15

Obs	TLE
1	1 25484U 98053K 15334.56853727 +.00000079 +00000-0 +65937-4 0 9997 2 25484 044.5323 004.2742 0065921 291.2478 202.7754 14.41475304904611
2	1 25484U 98053K 15335.54461584 .00000064 00000-0 61435-4 0 9995 2 25484 44.5322 359.5816 0065888 296.2431 228.0221 14.41475600905030
3	1 25484U 98053K 15335.61108157 +.00000061 +00000-0 +60553-4 0 9994 2 25484 044.5322 359.2621 0065886 296.5840 212.9376 14.41475614904763
4	1 25484U 98053K 15336.91214282 .00000045 00000-0 55834-4 0 9993 2 25484 44.5322 353.0071 0065834 303.2454 124.6435 14.41476015905238
5	1 25484U 98053K 15337.26580911 +.00000041 +00000-0 +54750-4 0 9999 2 25484 044.5321 351.3068 0065810 305.0544 159.9557 14.41476132905009
6	1 25484U 98053K 15338.01197766 .00000029 00000-0 50986-4 0 9998 2 25484 44.5321 347.7195 0065777 308.8846 72.1019 14.41476338905396
7	1 25484U 98053K 15339.13784946 .00000022 00000-0 49152-4 0 9990 2 25484 44.5321 342.3067 0065718 314.6725 154.6621 14.41476730905550
8	1 25484U 98053K 15339.89313376 +.00000051 +00000-0 +57757-4 0 9990 2 25484 044.5321 338.6756 0065677 318.5550 114.1100 14.41477153905380
9	1 25484U 98053K 15340.46403310 .00000060 00000-0 60349-4 0 9994 2 25484 44.5320 335.9309 0065636 321.4984 196.7080 14.41477397905745
10	1 25484U 98053K 15340.99346506 +.00000069 +00000-0 +62965-4 0 9990 2 25484 044.5320 333.3856 0065608 324.2206 064.1255 14.41477635905546
11	1 25484U 98053K 15341.83258545 .00000069 00000-0 63087-4 0 9995 2 25484 44.5320 329.3514 0065542 328.5330 98.6329 14.41477957905949

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 173. Ephemeris Data Derived From TLEs for #25484

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	13 : 38 : 41.620	14.4148	0.0065921	44.5323	291.2478	4.2742	202.7754
2	1-Dec	13 : 4 : 14.809	14.4148	65888	44.5322	296.2431	359.5816	228.0221
3	1-Dec	14 : 39 : 57.448	14.4148	65886	44.5322	296.5840	359.2621	212.9376
4	2-Dec	21 : 53 : 29.140	14.4148	65834	44.5322	303.2454	353.0071	124.6435
5	3-Dec	6 : 22 : 45.907	14.4148	65810	44.5321	305.0544	351.3068	159.9557
6	4-Dec	0 : 17 : 14.870	14.4148	65777	44.5321	308.8846	347.7195	72.1019
7	5-Dec	3 : 18 : 30.193	14.4148	65718	44.5321	314.6725	342.3067	154.6621
8	5-Dec	21 : 26 : 6.757	14.4148	65677	44.5321	318.5550	338.6756	114.1100
9	6-Dec	11 : 8 : 12.460	14.4148	65636	44.5320	321.4984	335.9309	196.7080
10	6-Dec	23 : 50 : 35.381	14.4148	65608	44.5320	324.2206	333.3856	64.1255
11	7-Dec	19 : 58 : 55.383	14.4148	65542	44.5320	328.5330	329.3514	98.6329

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 174. Error of Propagated Ephemeris for #25484

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.189	442	23.42589
→3	0.078	281	25.02106
→4	0.512	701	56.24653
→5	0.636	596	64.73452
→6	0.718	1588	82.64257
→7	1.263	999	109.66349
→8	1.414	1603	127.79032
→9	1.669	2307	141.49190
→10	1.532	2485	154.19827
→11	2.019	2575	174.33716
Obs 2→3	0.007	19	1.59518
→4	0.23	395	32.82065
→5	0.313	389	41.30864
→6	0.434	1132	59.21668
→7	0.767	808	86.23761
→8	0.865	1269	104.36443
→9	1.078	1982	118.06601
→10	1.006	2454	130.77238
→11	1.262	2178	150.91127
Obs 3→4	0.213	375	31.22547
→5	0.292	375	39.71346
→6	0.412	1101	57.62151
→7	0.722	795	84.64243
→8	0.811	1247	102.76925
→9	1.02	1959	116.47084
→10	0.953	2454	129.17720
→11	1.175	2152	149.31609

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.051	83	8.48799
→6	0.174	499	26.39604
→7	0.339	523	53.41696
→8	0.395	831	71.54378
→9	0.575	1483	85.24537
→10	0.601	1849	97.95173
→11	0.606	1644	118.09062
Obs 5→6	0.114	337	17.90805
→7	0.275	446	44.92897
→8	0.321	724	63.05579
→9	0.507	1347	76.75738
→10	0.537	1685	89.46374
→11	0.514	1510	109.60263
Obs 6→7	0.134	275	27.02092
→8	0.16	505	45.14775
→9	0.349	1050	58.84933
→10	0.42	1339	71.55570
→11	0.306	1236	91.69459
Obs 7→8	0.039	195	18.12682
→9	0.187	580	31.82841
→10	0.276	824	44.53477
→11	0.2	841	64.67366
Obs 8→9	0.095	253	13.70158
→10	0.167	484	26.40795
→11	0.256	590	46.54684
Obs 9→10	0.076	231	12.70637
→11	0.167	408	32.84526
Obs 10→11	0.142	245	20.13889

Figure 115. Error of the Two-Body Propagator Over Time–#25484

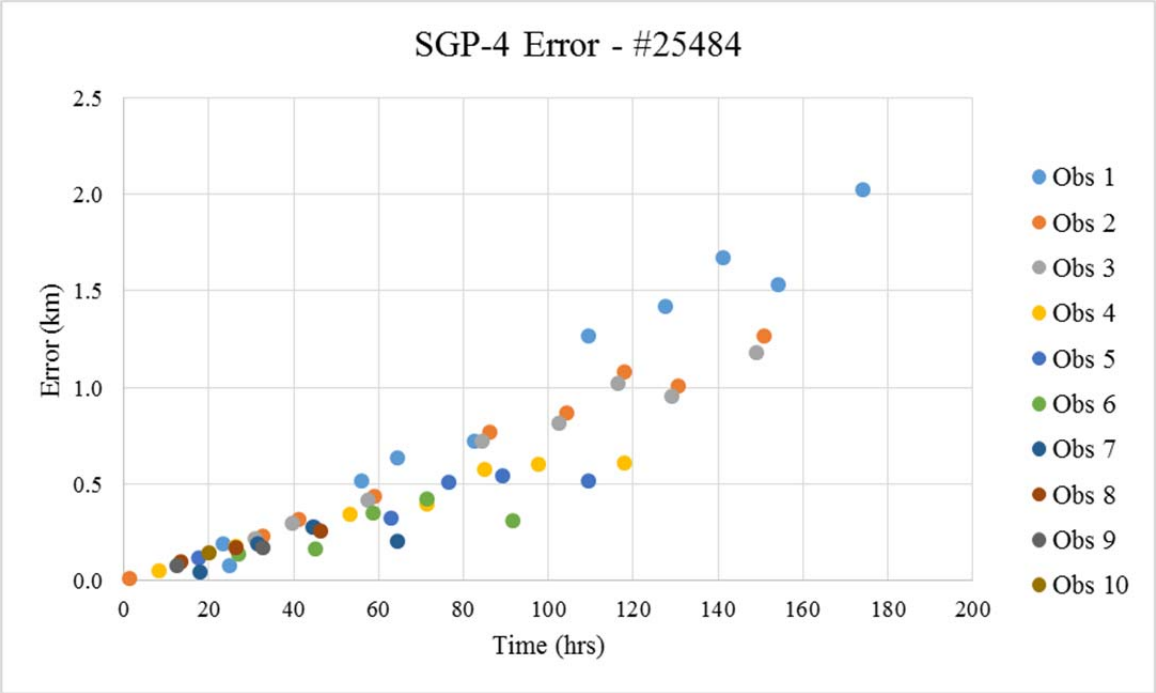

Figure 116. Error of the SGP-4 Propagator Over Time–#25484

GGG. CATALOG NUMBER 25490–TAURUS ROCKET BODY

This ephemeris data represents one of three samples for inclinations 80–90 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 175. Two-Line Element for #25490 30NOV–7DEC15

Obs	TLE
1	1 25490U 98055B 15335.82344906 +.00000290 +00000-0 +45866-4 0 9994 2 25490 085.0711 052.9906 0014379 335.0407 025.0109 14.68434696919570
2	1 25490U 98055B 15336.50488176 .00000273 00000-0 42836-4 0 9993 2 25490 85.0711 52.5792 0014306 332.5684 27.4772 14.68434968919954
3	1 25490U 98055B 15336.91374133 +.00000258 +00000-0 +40345-4 0 9991 2 25490 085.0711 052.3323 0014259 331.1013 028.9408 14.68435130919730
4	1 25490U 98055B 15337.73146040 .00000243 00000-0 37783-4 0 9992 2 25490 85.0711 51.8387 0014169 328.1187 31.9167 14.68435482920134
5	1 25490U 98055B 15338.75360905 .00000224 00000-0 34424-4 0 9991 2 25490 85.0710 51.2215 0014066 324.3553 35.6719 14.68435856920283
6	1 25490U 98055B 15339.84390059 .00000247 00000-0 38444-4 0 9996 2 25490 85.0710 50.5632 0013962 320.3338 39.6852 14.68436500920446
7	1 25490U 98055B 15340.79790546 +.00000286 +00000-0 +45150-4 0 9992 2 25490 085.0709 049.9871 0013872 316.7631 043.2492 14.68437130920302
8	1 25490U 98055B 15341.20676457 .00000288 00000-0 45527-4 0 9993 2 25490 85.0709 49.7403 0013837 315.2300 44.7794 14.68437352920643
9	1 25490U 98055B 15341.68376696 +.00000289 +00000-0 +45709-4 0 9990 2 25490 085.0709 049.4522 0013805 313.4278 046.5785 14.68437543920430

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 176. Ephemeris Data Derived From TLEs for #25490

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	19 : 45 : 45.999	14.6843	0.0014379	85.0711	335.0407	52.9906	25.0109
2	2-Dec	12 : 7 : 1.784	14.6843	14306	85.0711	332.5684	52.5792	27.4772
3	2-Dec	21 : 55 : 47.251	14.6844	14259	85.0711	331.1013	52.3323	28.9408
4	3-Dec	17 : 33 : 18.179	14.6844	14169	85.0711	328.1187	51.8387	31.9167
5	4-Dec	18 : 5 : 11.822	14.6844	14066	85.0710	324.3553	51.2215	35.6719
6	5-Dec	20 : 15 : 13.011	14.6844	13962	85.0710	320.3338	50.5632	39.6852
7	6-Dec	19 : 8 : 59.032	14.6844	13872	85.0709	316.7631	49.9871	43.2492
8	7-Dec	4 : 57 : 44.459	14.6844	13837	85.0709	315.2300	49.7403	44.7794
9	7-Dec	16 : 24 : 37.465	14.6844	13805	85.0709	313.4278	49.4522	46.5785

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 177. Error of Propagated Ephemeris for #25490

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.060	291	16.35438
→3	0.096	465	26.16701
→4	0.182	813	45.79227
→5	0.344	1248	70.32384
→6	0.520	1710	96.49084
→7	0.674	2112	119.38695
→8	0.754	2284	129.19957
→9	0.898	2484	140.64763
Obs 2→3	0.038	174	9.81263
→4	0.110	523	29.43789
→5	0.218	958	53.96945
→6	0.327	1421	80.13645
→7	0.420	1824	103.03257
→8	0.461	1997	112.84519
→9	0.541	2197	124.29324
Obs 3→4	0.075	352	19.62526
→5	0.166	792	44.15683
→6	0.258	1260	70.32382
→7	0.343	1668	93.21994
→8	0.377	1843	103.03256
→9	0.419	2046	114.48062
Obs 4→5	0.092	436	24.53157
→6	0.187	900	50.69856
→7	0.292	1305	73.59468
→8	0.336	1478	83.40730
→9	0.366	1680	94.85536
Obs 5→6	0.137	464	26.16700
→7	0.293	870	49.06311
→8	0.370	1044	58.87573
→9	0.414	1246	70.32379
Obs 6→7	0.095	406	22.89612
→8	0.138	580	32.70874
→9	0.166	783	44.15679
Obs 7→8	0.036	176	9.81262
→9	0.109	381	21.26068
Obs 8→9	0.086	205	11.44806

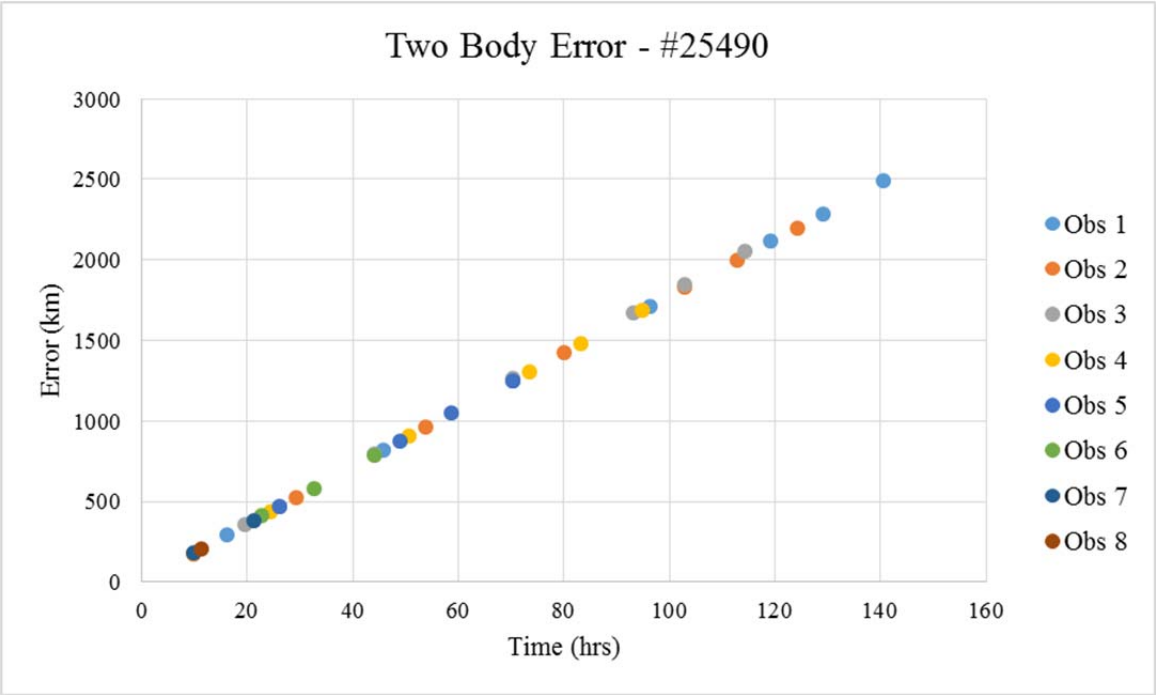

Figure 117. Error of the Two-Body Propagator Over Time–#25490

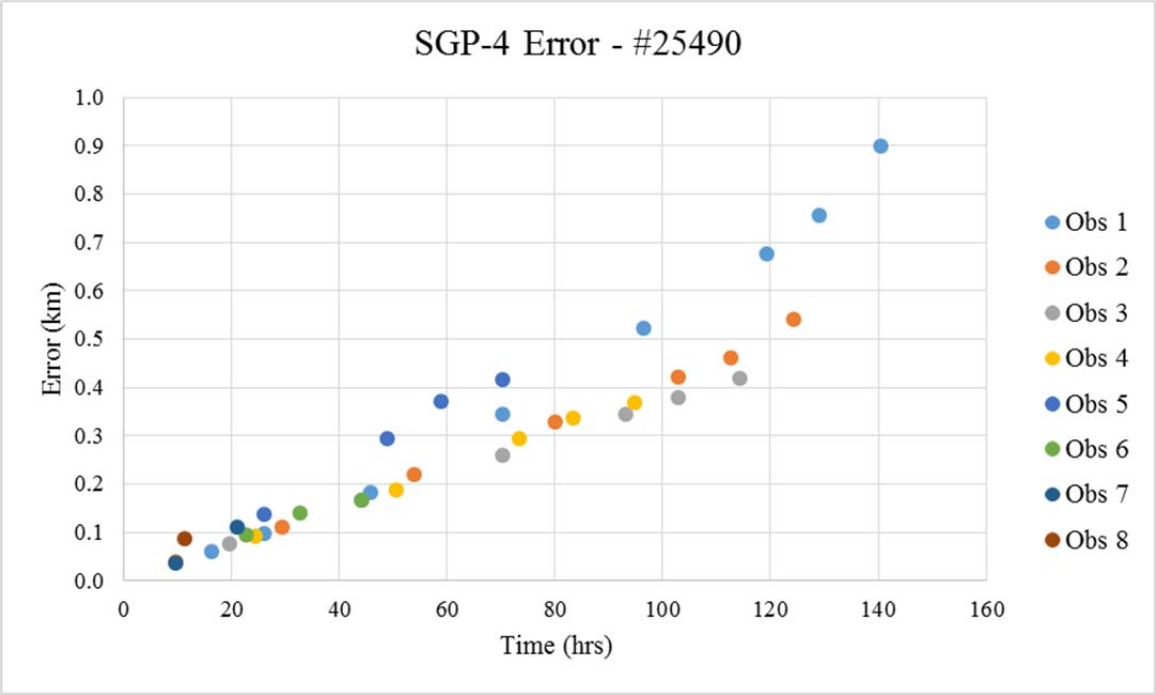

Figure 118. Error of the SGP-4 Propagator Over Time–#25490

HHH. CATALOG NUMBER 25504–SCD-2

This ephemeris data represents one of three samples for inclinations 20–30 degrees used in the experiment to determine the effect of inclination on propagator accuracy and is the orbit most similar to NPSAT-1.

Table 178. Two-Line Element for #25504 30NOV–7DEC15

Obs	TLEs
1	1 25504U 98060A 15335.38766894 +.00000310 +00000-0 +37114-4 0 9991
	2 25504 024.9969 015.2168 0017183 185.0991 295.5884 14.43925857903105
2	1 25504U 98060A 15336.20815391 .00000305 00000-0 35618-4 0 9991
	2 25504 24.9970 10.1704 0017135 193.7747 240.5507 14.43926005903488
3	1 25504U 98060A 15336.28092137 +.00000297 +00000-0 +33338-4 0 9991
	2 25504 024.9970 009.7228 0017132 194.5425 258.8046 14.43925977903232
4	1 25504U 98060A 15337.32160887 .00000298 00000-0 33451-4 0 9992
	2 25504 24.9970 3.3217 0017098 205.5569 268.3935 14.43926279903647
5	1 25504U 98060A 15339.17817336 .00000290 00000-0 31417-4 0 9997
	2 25504 24.9970 351.9026 0017002 225.3037 198.8885 14.43926684903913
6	1 25504U 98060A 15339.47191058 +.00000303 +00000-0 +35092-4 0 9994
	2 25504 024.9970 350.0957 0017010 228.4399 285.7348 14.43926833903691
7	1 25504U 98060A 15340.21860425 .00000303 00000-0 34917-4 0 9994
	2 25504 24.9970 345.5029 0017008 236.3751 207.0859 14.43926996904063
8	1 25504U 98060A 15340.36659584 +.00000308 +00000-0 +36393-4 0 9997
	2 25504 024.9971 344.5926 0017003 237.9685 256.3329 14.43927058903829
9	1 25504U 98060A 15341.40642336 .00000304 00000-0 35240-4 0 9996
	2 25504 24.9971 338.1970 0016979 249.1201 261.3075 14.43927258904239

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 179. Ephemeris Data Derived From TLEs for #25504

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	9 : 18 : 14.596	14.4393	0.0017183	24.9969	185.0991	15.2168	295.5884
2	2-Dec	4 : 59 : 44.498	14.4393	17135	24.9970	193.7747	10.1704	240.5507
3	2-Dec	6 : 44 : 31.606	14.4393	17132	24.9970	194.5425	9.7228	258.8046
4	3-Dec	7 : 43 : 7.006	14.4393	17098	24.9970	205.5569	3.3217	268.3935
5	5-Dec	4 : 16 : 34.178	14.4393	17002	24.9970	225.3037	351.9026	198.8885
6	5-Dec	11 : 19 : 33.074	14.4393	17010	24.9970	228.4399	350.0957	285.7348
7	6-Dec	5 : 14 : 47.407	14.4393	17008	24.9970	236.3751	345.5029	207.0859
8	6-Dec	8 : 47 : 53.881	14.4393	17003	24.9971	237.9685	344.5926	256.3329
9	7-Dec	9 : 45 : 14.978	14.4393	16979	24.9971	249.1201	338.1970	261.3075

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 180. Error of Propagated Ephemeris for #25504

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.054	516	19.69164
→3	0.016	550	21.43806
→4	0.161	1196	46.41456
→5	0.313	2483	90.97211
→6	0.579	2624	98.02180
→7	0.191	3058	115.94245
→8	0.519	3038	119.49425
→9	0.812	3715	144.45011
Obs 2→3	0.032	45	1.74642
→4	0.153	693	26.72292
→5	0.302	1936	71.28047
→6	0.515	2126	78.33016
→7	0.296	2530	96.25081
→8	0.518	2566	99.80261
→9	0.763	3257	124.75847
Obs 3→4	0.203	649	24.97650
→5	0.389	1887	69.53405
→6	0.574	2080	76.58374
→7	0.456	2483	94.50439
→8	0.625	2524	98.05619
→9	0.862	3216	123.01205
Obs 4→5	0.171	1200	44.55755
→6	0.324	1424	51.60724
→7	0.199	1818	69.52789
→8	0.362	1908	73.07969
→9	0.59	2610	98.03555
Obs 5→6	0.052	199	7.04969
→7	0.098	647	24.97034
→8	0.143	763	28.52214
→9	0.33	1466	53.47800
Obs 6→7	0.032	464	17.92065
→8	0.089	577	21.47245
→9	0.263	1278	46.42831
Obs 7→8	0.009	96	3.55180
→9	0.158	792	28.50766
Obs 8→9	0.142	694	24.95586

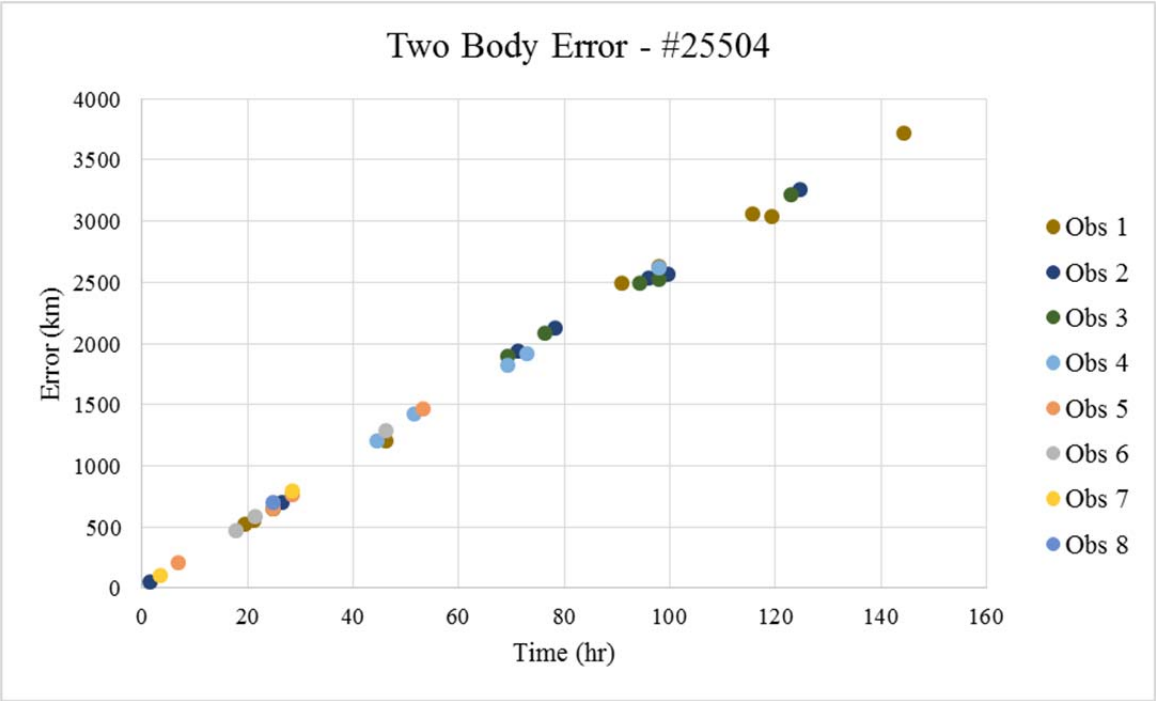

Figure 119. Error of the Two-Body Propagator Over Time–#25504

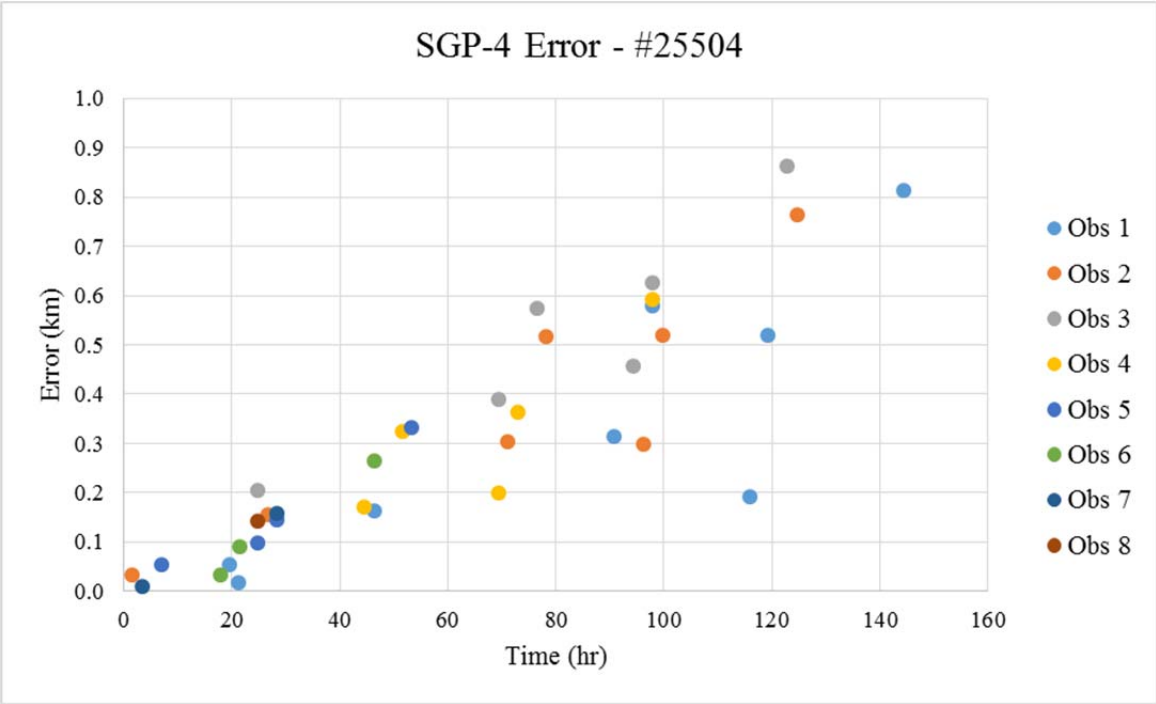

Figure 120. Error of the SGP-4 Propagator Over Time–#25504

III. CATALOG NUMBER 25527–IRIDIUM 2

This ephemeris data represents one of three samples for semi-major axes 6900–7000 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 181. Two-Line Element for #25527 30NOV–7DEC15

Obs	TLE
1	1 25527U 98066A 15334.92084019 +.00003612 +00000-0 +19716-3 0 9998
	2 25527 085.5305 004.7472 0010191 015.8729 038.8908 15.13960653932949
2	1 25527U 98066A 15335.53502192 .00003889 00000-0 21240-3 0 9994
	2 25527 85.5307 4.3860 0010057 13.7863 146.1800 15.13965237932515
3	1 25527U 98066A 15335.91218794 +.00004040 +00000-0 +22070-3 0 9990
	2 25527 085.5308 004.1643 0010006 012.3600 041.8867 15.13969019933091
4	1 25527U 98066A 15336.52662054 .00004247 00000-0 23210-3 0 9996
	2 25527 85.5310 3.8030 0009855 10.3478 150.4868 15.13973586932665
5	1 25527U 98066A 15336.90389231 +.00004086 +00000-0 +22318-3 0 9990
	2 25527 085.5311 003.5812 0009778 009.0832 046.6165 15.13976048933241
6	1 25527U 98066A 15337.30111476 .00003859 00000-0 21066-3 0 9995
	2 25527 85.5313 3.3477 0009705 7.6250 51.6089 15.13978662932789
7	1 25527U 98066A 15337.77440259 +.00003898 +00000-0 +21283-3 0 9994
	2 25527 085.5312 003.0694 0009667 005.8063 111.2698 15.13982456933376
8	1 25527U 98066A 15338.02817022 .00003568 00000-0 19460-3 0 9997
	2 25527 85.5313 2.9202 0009621 4.8463 54.4217 15.13983643932893
9	1 25527U 98066A 15338.88659565 +.00003298 +00000-0 +17970-3 0 9991
	2 25527 085.5314 002.4156 0009496 001.6396 053.2087 15.13989530933543
10	1 25527U 98066A 15339.15415979 .00003270 00000-0 17819-3 0 9993
	2 25527 85.5314 2.2583 0009458 0.6310 71.5615 15.13991513933069
11	1 25527U 98066A 15339.55847810 .00003651 00000-0 19916-3 0 9993
	2 25527 85.5314 2.0206 0009397 359.1065 115.2929 15.13995660933128
12	1 25527U 98066A 15339.87798303 +.00003875 +00000-0 +21148-3 0 9998
	2 25527 085.5314 001.8327 0009341 357.9548 056.7028 15.13998940933695
13	1 25527U 98066A 15340.55916751 .00003951 00000-0 21562-3 0 9999
	2 25527 85.5314 1.4322 0009252 355.3722 169.5209 15.14004274933270
14	1 25527U 98066A 15341.00251947 +.00004357 +00000-0 +23793-3 0 9998
	2 25527 085.5312 001.1715 0009196 353.7224 066.0051 15.14009261933869
15	1 25527U 98066A 15341.55000880 .00004050 00000-0 22103-3 0 9990
	2 25527 85.5313 0.8496 0009114 351.6080 170.1666 15.14012092933426

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 182. Ephemeris Data Derived From TLEs for #25527

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22 : 6 : 0.592	15.1396	0.0010191	85.5305	15.8729	4.7472	38.8908
2	1-Dec	12 : 50 : 25.894	15.1397	10057	85.5307	13.7863	4.3860	146.1800
3	1-Dec	21 : 53 : 33.038	15.1397	10006	85.5308	12.3600	4.1643	41.8867
4	2-Dec	12 : 38 : 20.015	15.1397	9855	85.5310	10.3478	3.8030	150.4868
5	2-Dec	21 : 41 : 36.296	15.1398	9778	85.5311	9.0832	3.5812	46.6165
6	3-Dec	7 : 13 : 36.315	15.1398	9705	85.5313	7.6250	3.3477	51.6089
7	3-Dec	18 : 35 : 8.384	15.1398	9667	85.5312	5.8063	3.0694	111.2698
8	4-Dec	0 : 40 : 33.907	15.1398	9621	85.5313	4.8463	2.9202	54.4217
9	4-Dec	21 : 16 : 41.864	15.1399	9496	85.5314	1.6396	2.4156	53.2087
10	5-Dec	3 : 41 : 59.406	15.1399	9458	85.5314	0.6310	2.2583	71.5615
11	5-Dec	13 : 24 : 12.508	15.1400	9397	85.5314	359.1065	2.0206	115.2929
12	5-Dec	21 : 4 : 17.734	15.1400	9341	85.5314	357.9548	1.8327	56.7028
13	6-Dec	13 : 25 : 12.073	15.1400	9252	85.5314	355.3722	1.4322	169.5209
14	7-Dec	0 : 3 : 37.682	15.1401	9196	85.5312	353.7224	1.1715	66.0051
15	7-Dec	13 : 12 : 0.760	15.1401	9114	85.5313	351.6080	0.8496	170.1666

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 183. Error of Propagated Ephemeris for #25527

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.338	277	14.74036
→3	0.259	443	23.79235
→4	0.240	721	38.53873
→5	0.358	882	47.59325
→6	0.290	1055	57.12659
→7	0.197	1264	68.48550
→8	0.395	1372	74.57592
→9	0.821	1745	95.17813
→10	0.989	1856	101.59967
→11	1.256	2036	111.30331
→12	1.759	2168	118.97143
→13	3.290	2485	135.31986
→14	3.223	2640	145.96030
→15	4.779	2904	159.10005
Obs 2→3	0.116	170	9.05198
→4	0.139	449	23.79837
→5	0.265	613	32.85289
→6	0.346	789	42.38623
→7	0.351	1000	53.74514
→8	0.263	1110	59.83556
→9	0.395	1485	80.43777
→10	0.480	1600	86.85931
→11	0.669	1781	96.56295
→12	0.532	1916	104.23107
→13	0.550	2232	120.57949
→14	0.463	2395	131.21994
→15	0.659	2658	144.35969
Obs 3→4	0.341	278	14.74638
→5	0.789	444	23.80090
→6	1.075	620	33.33424
→7	1.340	830	44.69315
→8	1.395	941	50.78357
→9	2.126	1319	71.38579
→10	2.455	1432	77.80732
→11	2.967	1612	87.51096
→12	3.090	1748	95.17908
→13	3.282	2063	111.52751
→14	4.097	2228	122.16796
→15	4.226	2490	135.30770
Obs 4→5	0.282	169	9.05452
→6	0.540	345	18.58786
→7	0.838	555	29.94677
→8	0.890	666	36.03719
→9	1.786	1044	56.63940
→10	2.179	1159	63.06094
→11	2.880	1338	72.76458
→12	3.097	1475	80.43270
→13	3.839	1788	96.78113
→14	4.713	1957	107.42157
→15	5.435	2216	120.56132
Obs 5→6	0.122	178	9.53334
→7	0.236	390	20.89225
Obs 5→8	0.178	503	26.98267
→9	0.615	885	47.58488
→10	0.831	1001	54.00642
→11	1.286	1182	63.71006
→12	1.266	1321	71.37818
→13	1.599	1635	87.72660
→14	1.965	1808	98.36705
→15	2.314	2067	111.50680
Obs 6→7	0.047	212	11.35891
→8	0.212	325	17.44933
→9	0.217	707	38.05154
→10	0.164	823	44.47308
→11	0.083	1004	54.17672
→12	0.264	1143	61.84484
→13	0.504	1456	78.19327
→14	0.537	1632	88.83371
→15	0.791	1889	101.97346
Obs 7→8	0.118	113	6.09042
→9	0.090	495	26.69263
→10	0.095	612	33.11417
→11	0.295	792	42.81781
→12	0.171	932	50.48593
→13	0.278	1243	66.83436
→14	0.167	1421	77.47481
→15	0.382	1676	90.61455
Obs 8→9	0.294	382	20.60221
→10	0.401	499	27.02375
→11	0.466	679	36.72739
→12	0.914	819	44.39551
→13	1.637	1129	60.74393
→14	2.189	1309	71.38438
→15	2.925	1563	84.52413
Obs 9→10	0.170	119	6.42154
→11	0.321	300	16.12518
→12	0.825	442	23.79330
→13	1.722	751	40.14172
→14	2.616	938	50.78217
→15	3.589	1190	63.92192
Obs 10→11	0.116	180	9.70364
→12	0.580	323	17.37176
→13	1.402	630	33.72019
→14	2.296	819	44.36063
→15	3.211	1070	57.50038
Obs 11→12	0.220	143	7.66812
→13	0.409	453	24.01655
→14	0.870	645	34.65699
→15	1.075	897	47.79674
Obs 12→13	0.216	308	16.34843
→14	0.079	502	26.98887
→15	0.245	752	40.12862
Obs 13→14	0.304	197	10.64045
→15	0.111	445	23.78019
Obs 14→15	0.822	246	13.13974

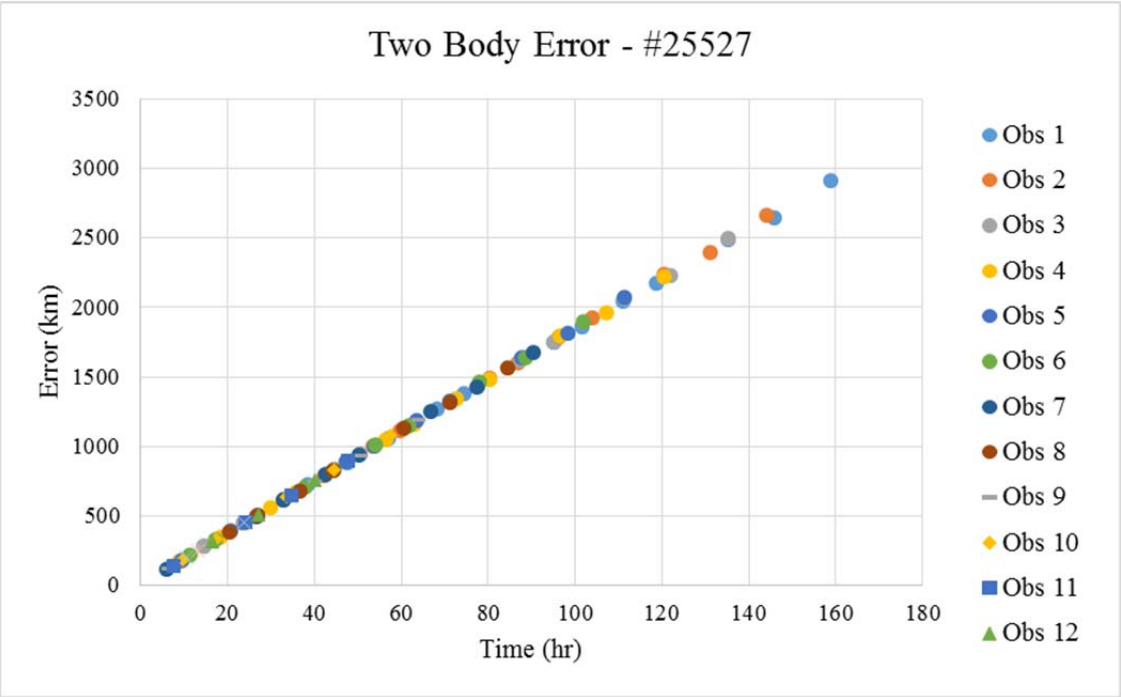

Figure 121. Error of the Two-Body Propagator Over Time–#25527

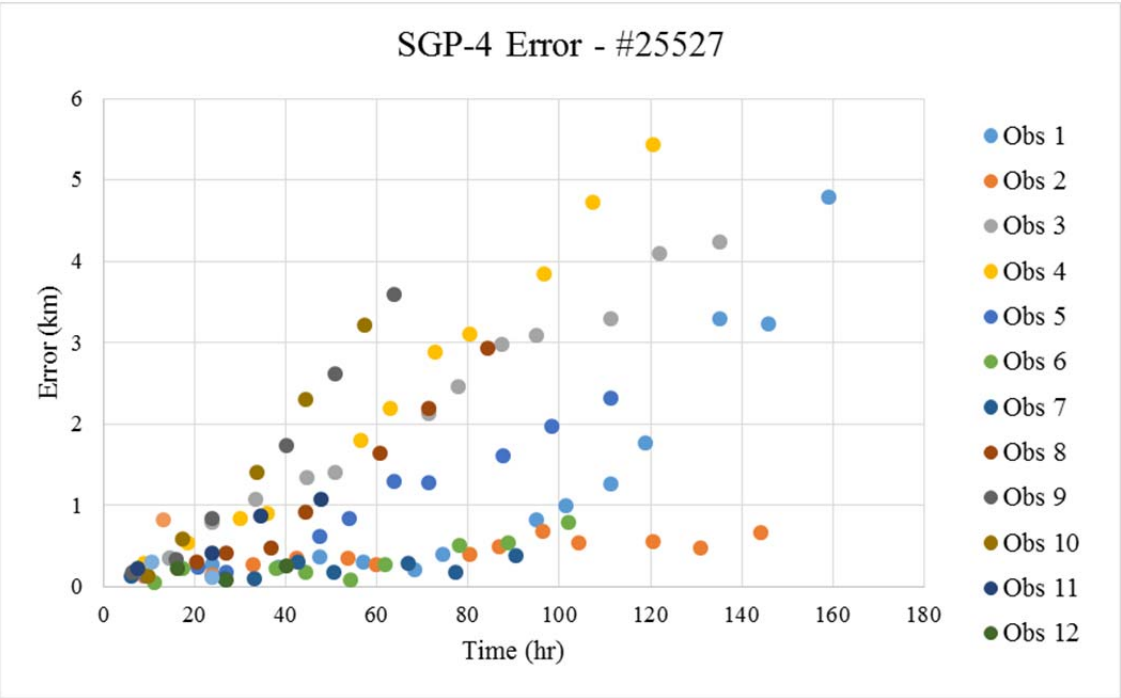

Figure 122. Error of the SGP-4 Propagator Over Time–#25527

JJJ. CATALOG NUMBER 25777–IRIDIUM 14

This ephemeris data represents one of three samples for semi-major axes 7100–7200 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 184. Two-Line Element for #25777 30NOV–7DEC15

Obs	TLE
1	1 25777U 99032A 15335.50012204 .00000041 00000-0 74811-5 0 9993 2 25777 86.3972 99.6019 0002124 91.6603 318.7313 14.34210562873881
2	1 25777U 99032A 15335.87008155 +.00000038 +00000-0 +65310-5 0 9993 2 25777 086.3974 099.4474 0002124 091.6199 067.7238 14.34210570873859
3	1 25777U 99032A 15336.54866630 .00000037 00000-0 60293-5 0 9992 2 25777 86.3967 99.1628 0002134 91.2638 329.5076 14.34210860874036
4	1 25777U 99032A 15336.90703074 +.00000036 +00000-0 +59425-5 0 9998 2 25777 086.3968 099.0130 0002138 091.4634 018.4319 14.34210979874008
5	1 25777U 99032A 15337.31725021 .00000036 00000-0 57498-5 0 9998 2 25777 86.3971 98.8423 0002100 90.1906 336.3957 14.34211659874142
6	1 25777U 99032A 15337.88318953 .00000034 00000-0 49675-5 0 9998 2 25777 86.3971 98.6056 0002108 90.3380 16.4393 14.34212153874227
7	1 25777U 99032A 15338.92920071 +.00000028 +00000-0 +27996-5 0 9999 2 25777 086.3971 098.1683 0002115 090.9219 013.1695 14.34212205874297
8	1 25777U 99032A 15339.20214137 .00000027 00000-0 26389-5 0 9994 2 25777 86.3971 98.0542 0002102 90.2394 342.1989 14.34212273874413
9	1 25777U 99032A 15339.55494150 .00000024 00000-0 16387-5 0 9991 2 25777 86.3972 97.9067 0002103 90.7232 2.1295 14.34212338874461
10	1 25777U 99032A 15339.90417397 +.00000023 +00000-0 +10245-5 0 9994 2 25777 086.3972 097.7608 0002119 091.4439 003.4149 14.34212466874435
11	1 25777U 99032A 15340.52596378 .00000278 00000-0 92335-4 0 9992 2 25777 86.3973 97.5010 0002114 91.0406 332.1953 14.34213515874606
12	1 25777U 99032A 15341.01230411 +.00000288 +00000-0 +95687-4 0 9994 2 25777 086.3973 097.2977 0002113 090.8939 321.8126 14.34213849874597
13	1 25777U 99032A 15341.51609475 .00000284 00000-0 94254-4 0 9994 2 25777 86.3974 97.0872 0002112 91.0141 41.2051 14.34214079874740

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 185. Ephemeris Data Derived From TLEs for #25777

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	12 : 0 : 10.544	14.3421	0.0002124	86.3972	91.6603	99.6019	318.7313
2	1-Dec	20 : 52 : 55.046	14.3421	2124	86.3974	91.6199	99.4474	67.7238
3	2-Dec	13 : 10 : 4.768	14.3421	2134	86.3967	91.2638	99.1628	329.5076
4	2-Dec	21 : 46 : 7.456	14.3421	2138	86.3968	91.4634	99.0130	18.4319
5	3-Dec	7 : 36 : 50.418	14.3421	2100	86.3971	90.1906	98.8423	336.3957
6	3-Dec	21 : 11 : 47.575	14.3421	2108	86.3971	90.3380	98.6056	16.4393
7	4-Dec	22 : 18 : 2.941	14.3421	2115	86.3971	90.9219	98.1683	13.1695
8	5-Dec	4 : 51 : 5.014	14.3421	2102	86.3971	90.2394	98.0542	342.1989
9	5-Dec	13 : 19 : 6.946	14.3421	2103	86.3972	90.7232	97.9067	2.1295
10	5-Dec	21 : 42 : 0.631	14.3421	2119	86.3972	91.4439	97.7608	3.4149
11	6-Dec	12 : 37 : 23.271	14.3421	2114	86.3973	91.0406	97.5010	332.1953
12	7-Dec	0 : 17 : 43.075	14.3421	2113	86.3973	90.8939	97.2977	321.8126
13	7-Dec	12 : 23 : 10.586	14.3421	2112	86.3974	91.0141	97.0872	41.2051

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 186. Error of Propagated Ephemeris for #25777

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.051	146	8.87903
→3	0.054	424	25.16506
→4	0.144	571	33.76581
→5	0.322	739	43.61108
→6	0.613	970	57.19362
→7	1.159	1398	82.29789
→8	1.351	1508	88.84846
→9	1.571	1652	97.31567
→10	1.862	1794	105.69725
→11	2.659	2048	120.62020
→12	3.329	2247	132.29237
→13	4.135	2458	144.38335
Obs 2→3	0.112	279	16.28603
→4	0.214	426	24.88678
→5	0.395	594	34.73205
→6	0.695	826	48.31459
→7	1.250	1254	73.41886
→8	1.449	1365	79.96944
→9	1.672	1508	88.43664
→10	1.967	1651	96.81822
→11	2.773	1904	111.74117
→12	3.447	2104	123.41334
→13	4.236	2314	135.50432
Obs 3→4	0.025	147	8.60075
→5	0.195	316	18.44601
→6	0.423	547	32.02856
→7	0.847	976	57.13283
→8	1.028	1087	63.68340
→9	1.204	1231	72.15060
→10	1.455	1374	80.53218
→11	2.196	1628	95.45514
→12	2.808	1828	107.12731
→13	3.485	2037	119.21828
Obs 4→5	0.158	168	9.84527
→6	0.360	400	23.42781
→7	0.733	829	48.53208
→8	0.908	941	55.08266
→9	1.065	1084	63.54986
→10	1.298	1227	71.93144
Obs 4→11	2.012	1482	86.85439
→12	2.598	1682	98.52656
→13	3.218	1891	110.61754
Obs 5→6	0.073	232	13.58254
→7	0.147	661	38.68681
→8	0.205	773	45.23739
→9	0.276	917	53.70459
→10	0.411	1059	62.08617
→11	0.911	1314	77.00913
→12	1.346	1514	88.68129
→13	1.890	1723	100.77227
Obs 6→7	0.162	429	25.10427
→8	0.148	541	31.65484
→9	0.147	685	40.12205
→10	0.096	828	48.50363
→11	0.297	1083	63.42658
→12	0.624	1283	75.09875
→13	1.018	1491	87.18973
Obs 7→8	0.020	112	6.55058
→9	0.020	256	15.01778
→10	0.070	399	23.39936
→11	0.433	655	38.32231
→12	0.743	855	49.99448
→13	1.074	1062	62.08546
Obs 8→9	0.014	145	8.46720
→10	0.046	288	16.84878
→11	0.375	543	31.77174
→12	0.668	743	43.44391
→13	1.009	950	55.53488
Obs 9→10	0.038	143	8.38158
→11	0.346	398	23.30453
→12	0.619	598	34.97670
→13	0.934	805	47.06768
Obs 10→11	0.278	255	14.92296
→12	0.518	455	26.59512
→13	0.762	662	38.68610
Obs 11→12	0.037	200	11.67217
→13	0.119	407	23.76314
Obs 12→13	0.104	207	12.09098

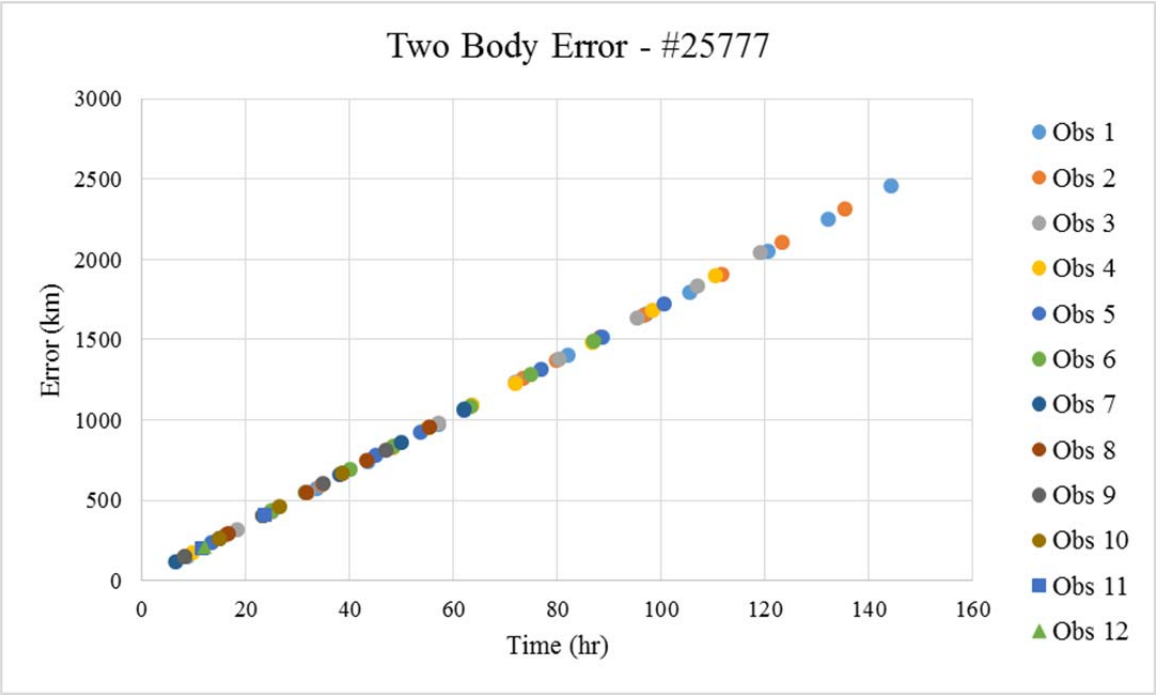

Figure 123. Error of the Two-Body Propagator Over Time–#25777

Figure 124. Error of the SGP-4 Propagator Over Time–#25777

KKK. CATALOG NUMBER 25791–FUSE 1

This ephemeris data represents one of three samples for inclinations 20–30 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 187. Two-Line Element for #25791 30NOV–7DEC15

Obs	TLE
1	1 25791U 99035A 15334.90566727 +.00000327 +00000-0 +43295-4 0 9997 2 25791 024.9849 266.7548 0010251 216.7292 192.6183 14.42635319867074
2	1 25791U 99035A 15335.26734001 .00000309 00000-0 37806-4 0 9990 2 25791 24.9849 264.5346 0010240 220.5939 270.9012 14.42635311867146
3	1 25791U 99035A 15335.94703970 +.00000303 +00000-0 +36103-4 0 9999 2 25791 024.9848 260.3623 0010219 227.8707 200.7870 14.42635441867222
4	1 25791U 99035A 15336.84102862 .00000293 00000-0 33110-4 0 9995 2 25791 24.9847 254.8745 0010192 237.4551 163.5290 14.42635600867373
5	1 25791U 99035A 15336.91472647 +.00000290 +00000-0 +32432-4 0 9997 2 25791 024.9846 254.4221 0010191 238.2380 186.2704 14.42635610867367
6	1 25791U 99035A 15337.88240815 .00000284 00000-0 30566-4 0 9993 2 25791 24.9845 248.4818 0010167 248.6292 171.7038 14.42635780867526
7	1 25791U 99035A 15337.95614314 +.00000276 +00000-0 +28220-4 0 9995 2 25791 024.9845 248.0292 0010166 249.4439 194.6067 14.42635764867516
8	1 25791U 99035A 15338.92382370 +.00000269 +00000-0 +26212-4 0 9998 2 25791 024.9843 242.0889 0010162 259.8299 180.0403 14.42635918867654
9	1 25791U 99035A 15339.14509742 .00000270 00000-0 26469-4 0 9993 2 25791 24.9842 240.7305 0010165 262.1887 249.1927 14.42635983867700
10	1 25791U 99035A 15339.96525748 +.00000284 +00000-0 +30487-4 0 9997 2 25791 024.9841 235.6957 0010166 270.9966 188.5071 14.42636214867806
11	1 25791U 99035A 15341.00711787 .00000293 00000-0 33212-4 0 9994 2 25791 24.9839 229.2999 0010170 282.1691 199.1888 14.42636464867972

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 188. Ephemeris Data Derived From TLEs for #25791

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 44 : 9.652	14.4264	0.0010251	24.9849	216.7292	266.7548	192.6183
2	1-Dec	6 : 24 : 58.177	14.4264	10240	24.9849	220.5939	264.5346	270.9012
3	1-Dec	22 : 43 : 44.230	14.4264	10219	24.9848	227.8707	260.3623	200.7870
4	2-Dec	20 : 11 : 4.873	14.4264	10192	24.9847	237.4551	254.8745	163.5290
5	2-Dec	21 : 57 : 12.367	14.4264	10191	24.9846	238.2380	254.4221	186.2704
6	3-Dec	21 : 10 : 40.064	14.4264	10167	24.9845	248.6292	248.4818	171.7038
7	3-Dec	22 : 56 : 50.767	14.4264	10166	24.9845	249.4439	248.0292	194.6067
8	4-Dec	22 : 10 : 18.368	14.4264	10162	24.9843	259.8299	242.0889	180.0403
9	5-Dec	3 : 28 : 56.417	14.4264	10165	24.9842	262.1887	240.7305	249.1927
10	5-Dec	23 : 9 : 58.246	14.4264	10166	24.9841	270.9966	235.6957	188.5071
11	7-Dec	0 : 10 : 14.984	14.4264	10170	24.9839	282.1691	229.2999	199.1888

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 189. Error of Propagated Ephemeris for #25791

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.05	233	8.68015
→3	0.08	661	24.99294
→4	0.257	1303	46.44867
→5	0.148	1292	48.21742
→6	0.332	1952	71.44178
→7	0.204	1909	73.21142
→8	0.378	2538	96.43575
→9	0.752	2691	101.74632
→10	0.536	3107	121.43017
→11	0.938	3653	146.43481
Obs 2→3	0.035	430	16.31279
→4	0.18	1057	37.76853
→5	0.099	1056	39.53728
→6	0.195	1711	62.76164
→7	0.05	1680	64.53128
→8	0.08	2305	87.75561
→9	0.594	2476	93.06618
→10	0.191	2884	112.75002
→11	0.605	3447	137.75467
Obs 3→4	0.111	597	21.45573
→5	0.076	617	23.22448
→6	0.148	1259	46.44884
→7	0.07	1252	48.21848
→8	0.062	1870	71.44282
→9	0.496	2065	76.75339
→10	0.169	2466	96.43723
→11	0.532	3057	121.44188

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.007	47	1.76875
→6	0.076	672	24.99311
→7	0.039	692	26.76275
→8	0.057	1302	49.98708
→9	0.369	1508	55.29765
→10	0.177	1917	74.98149
→11	0.473	2539	99.98614
Obs 5→6	0.08	624	23.22436
→7	0.04	646	24.99400
→8	0.063	1256	48.21833
→9	0.352	1462	53.52890
→10	0.173	1872	73.21274
→11	0.462	2496	98.21739
Obs 6→7	0.011	46	1.76964
→8	0.053	648	24.99397
→9	0.211	838	30.30454
→10	0.174	1279	49.98838
→11	0.403	1925	74.99303
Obs 7→8	0.058	602	23.22433
→9	0.207	790	28.53490
→10	0.202	1234	48.21874
→11	0.438	1881	73.22339
Obs 8→9	0.06	149	5.31057
→10	0.144	640	24.99441
→11	0.346	1298	49.99906
Obs 9→10	0.078	505	19.68384
→11	0.268	1163	44.68849
Obs 10→11	0.129	656	25.00465

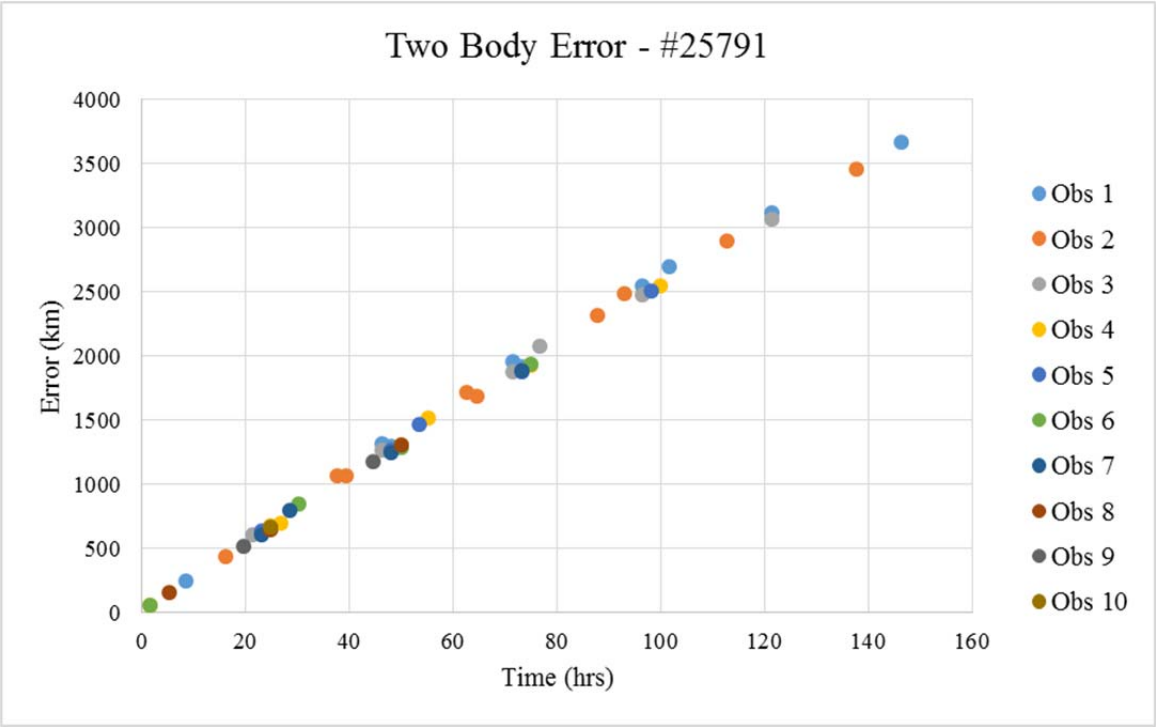

Figure 125. Error of the Two-Body Propagator Over Time–#25791

Figure 126. Error of the SGP-4 Propagator Over Time–#25791

LLL. CATALOG NUMBER 26365–SIMSAT 1

This ephemeris data represents one of three samples for semi-major axes 6800–6900 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 190. Two-Line Element for #26365 30NOV–7DEC15

Obs	TLE
1	1 26365U 00026A 15334.89300859 +.00000729 +00000-0 +35016-4 0 9995
	2 26365 086.3495 199.4402 0008602 321.6491 169.7074 15.16986479857482
2	1 26365U 00026A 15335.47458491 .00000762 00000-0 36682-4 0 9993
	2 26365 86.3494 199.1596 0008529 319.1227 106.1476 15.16987425857808
3	1 26365U 00026A 15335.88182620 +.00000782 +00000-0 +37713-4 0 9994
	2 26365 086.3494 198.9632 0008477 317.2921 170.4717 15.16988069857636
4	1 26365U 00026A 15336.80617794 .00000764 00000-0 36795-4 0 9991
	2 26365 86.3493 198.5172 0008373 313.1509 179.2056 15.16989036858002
5	1 26365U 00026A 15336.87132054 +.00000769 +00000-0 +37013-4 0 9998
	2 26365 086.3493 198.4858 0008366 312.8199 175.0482 15.16989110857789
6	1 26365U 00026A 15337.71309661 +.00000809 +00000-0 +39066-4 0 9997
	2 26365 086.3491 198.0797 0008283 309.0022 092.8111 15.16990317857917
7	1 26365U 00026A 15338.05686387 .00000764 00000-0 36807-4 0 9998
	2 26365 86.3491 197.9138 0008251 307.4327 170.4717 15.16990470858195
8	1 26365U 00026A 15339.11175127 .00000760 00000-0 36567-4 0 9990
	2 26365 86.3489 197.4049 0008155 302.5917 172.3086 15.16991821858351
9	1 26365U 00026A 15339.75875245 +.00000909 +00000-0 +44122-4 0 9999
	2 26365 086.3488 197.0927 0008095 299.5909 106.2914 15.16993641858224
10	1 26365U 00026A 15341.02540993 .00000940 00000-0 45696-4 0 9993
	2 26365 86.3486 196.4815 0007991 293.5100 185.1111 15.16996027858644

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 191. Ephemeris Data Derived From TLEs for #26365

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 25 : 55.942	15.1699	0.0008602	86.3495	321.6491	199.4402	169.7074
2	1-Dec	11 : 23 : 24.136	15.1699	8529	86.3494	319.1227	199.1596	106.1476
3	1-Dec	21 : 9 : 49.784	15.1699	8477	86.3494	317.2921	198.9632	170.4717
4	2-Dec	19 : 20 : 53.774	15.1699	8373	86.3493	313.1509	198.5172	179.2056
5	2-Dec	20 : 54 : 42.095	15.1699	8366	86.3493	312.8199	198.4858	175.0482
6	3-Dec	17 : 6 : 51.547	15.1699	8283	86.3491	309.0022	198.0797	92.8111
7	4-Dec	1 : 21 : 53.038	15.1699	8251	86.3491	307.4327	197.9138	170.4717
8	5-Dec	2 : 40 : 55.310	15.1699	8155	86.3489	302.5917	197.4049	172.3086
9	5-Dec	18 : 12 : 36.212	15.1699	8095	86.3488	299.5909	197.0927	106.2914
10	7-Dec	0 : 36 : 35.418	15.1700	7991	86.3486	293.5100	196.4815	185.1111

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 192. Error of Propagated Ephemeris for #26365

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.277	263	13.95783
→3	0.398	448	23.73162
→4	0.830	866	45.91606
→5	0.920	895	47.47949
→6	1.260	1274	67.68211
→7	1.551	1427	75.93253
→8	1.951	1898	101.24982
→9	1.869	2186	116.77785
→10	1.539	2747	147.17763
Obs 2→3	0.166	184	9.77379
→4	0.688	603	31.95823
→5	0.779	632	33.52166
→6	1.206	1012	53.72428
→7	1.542	1165	61.97470
→8	2.101	1637	87.29199
→9	2.114	1927	102.82002
→10	2.054	2490	133.21980
Obs 3→4	0.558	418	22.18444
→5	0.648	447	23.74786
→6	1.119	828	43.95049
→7	1.467	981	52.20090
→8	2.101	1454	77.51820
→9	2.165	1744	93.04623
→10	2.246	2307	123.44601

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.072	29	1.56342
→6	0.409	410	21.76605
→7	0.657	564	30.01646
→8	1.077	1038	55.33376
→9	1.010	1329	70.86179
→10	0.831	1893	101.26157
Obs 5→6	0.341	380	20.20263
→7	0.577	535	28.45304
→8	0.994	1009	53.77034
→9	0.934	1300	69.29837
→10	0.759	1850	99.69815
Obs 6→7	0.193	155	8.25041
→8	0.633	629	33.56771
→9	0.622	921	49.09574
→10	0.552	1487	79.49552
Obs 7→8	0.249	475	25.31730
→9	0.156	766	40.84533
→10	0.381	1332	71.24511
Obs 8→9	0.181	291	15.52803
→10	0.719	859	45.92781
Obs 9→10	0.092	568	30.39978

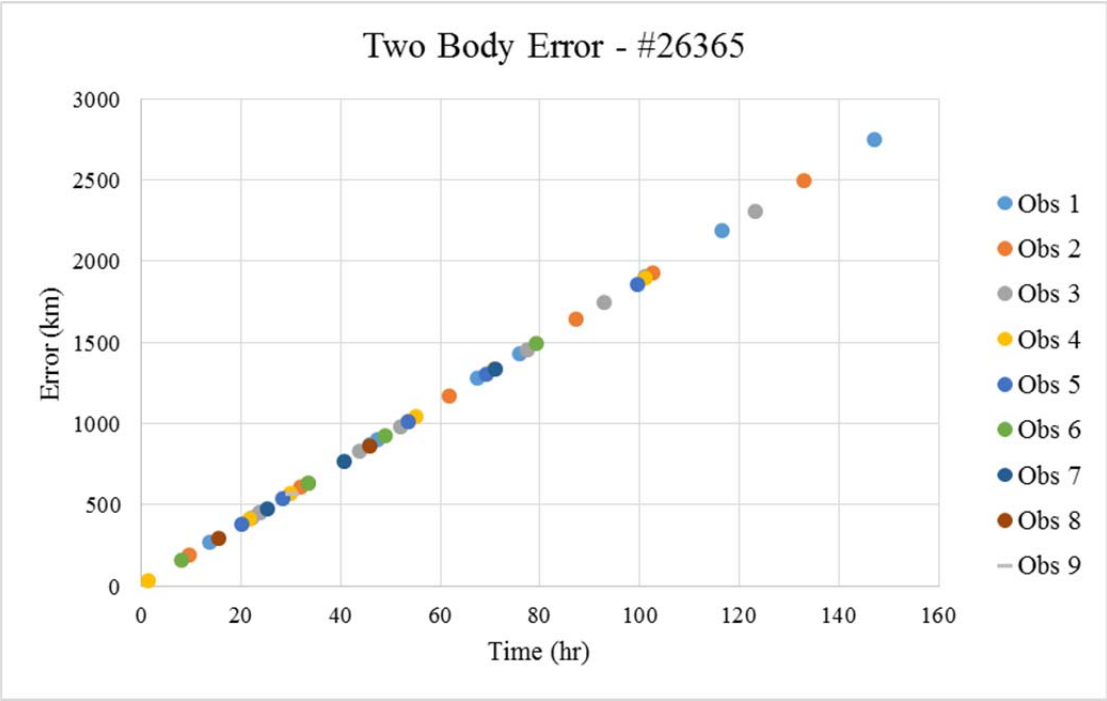

Figure 127. Error of the Two-Body Propagator Over Time–#26365

Figure 128. Error of the SGP-4 Propagator Over Time–#26365

MMM. CATALOG NUMBER 26366–SIMSAT 2

This ephemeris data represents one of three samples for semi-major axes 6800–6900 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 193. Two-Line Element for #26366 30NOV–7DEC15

Obs	TLE
1	1 26366U 00026B 15334.88799398 +.00000791 +00000-0 +37212-4 0 9994
	2 26366 086.3514 197.2971 0005035 248.3686 243.6017 15.17896103857901
2	1 26366U 00026B 15335.87611818 .00000833 00000-0 39246-4 0 9990
	2 26366 86.3512 196.8200 0005094 242.9670 244.8584 15.17897869858292
3	1 26366U 00026B 15336.93009296 +.00000793 +00000-0 +37301-4 0 9994
	2 26366 086.3511 196.3111 0005175 237.4107 245.8647 15.17899059858217
4	1 26366U 00026B 15337.12699512 .00000795 00000-0 37369-4 0 9998
	2 26366 86.3510 196.2160 0005195 236.4492 242.0524 15.17899335858486
5	1 26366U 00026B 15337.70637428 +.00000814 +00000-0 +38329-4 0 9999
	2 26366 086.3509 195.9362 0005242 233.4383 168.8877 15.17900178858331
6	1 26366U 00026B 15338.04962435 +.00000762 +00000-0 +35731-4 0 9992
	2 26366 086.3509 195.7705 0005276 231.7138 245.0033 15.17900310858381
7	1 26366U 00026B 15339.10405890 .00000745 00000-0 34888-4 0 9990
	2 26366 86.3507 195.2612 0005389 226.4265 248.2638 15.17901654858780
8	1 26366U 00026B 15339.89770095 +.00000885 +00000-0 +41802-4 0 9997
	2 26366 086.3506 194.8779 0005478 222.4125 266.1427 15.17903700858664
9	1 26366U 00026B 15340.54469497 .00000903 00000-0 42719-4 0 9991
	2 26366 86.3505 194.5654 0005560 219.2295 202.3869 15.17904877859003
10	1 26366U 00026B 15341.01681541 +.00000929 +00000-0 +43998-4 0 9998
	2 26366 086.3504 194.3374 0005622 216.9622 262.7810 15.17905917858838
11	1 26366U 00026B 15341.66569237 .00000873 00000-0 41241-4 0 9993
	2 26366 86.3503 194.0240 0005716 213.8298 209.2602 15.17906682859178

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 194. Ephemeris Data Derived From TLEs for #26366

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 18 : 42.680	15.1790	0.0005035	86.3514	248.3686	197.2971	243.6017
2	1-Dec	21 : 1 : 36.611	15.1790	5094	86.3512	242.9670	196.8200	244.8584
3	2-Dec	22 : 19 : 20.032	15.1790	5175	86.3511	237.4107	196.3111	245.8647
4	3-Dec	3 : 2 : 52.378	15.1790	5195	86.3510	236.4492	196.2160	242.0524
5	3-Dec	16 : 57 : 10.738	15.1790	5242	86.3509	233.4383	195.9362	168.8877
6	4-Dec	1 : 11 : 27.544	15.1790	5276	86.3509	231.7138	195.7705	245.0033
7	5-Dec	2 : 29 : 50.689	15.1790	5389	86.3507	226.4265	195.2612	248.2638
8	5-Dec	21 : 32 : 41.362	15.1790	5478	86.3506	222.4125	194.8779	266.1427
9	6-Dec	13 : 4 : 21.645	15.1790	5560	86.3505	219.2295	194.5654	202.3869
10	7-Dec	0 : 24 : 12.851	15.1791	5622	86.3504	216.9622	194.3374	262.7810
11	7-Dec	15 : 58 : 35.821	15.1791	5716	86.3503	213.8298	194.0240	209.2602

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 195. Error of Propagated Ephemeris for #26366

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.245	447	23.71498
→3	0.688	923	49.01038
→4	0.791	1011	53.73603
→5	0.986	1274	67.64113
→6	1.242	1426	75.87913
→7	1.699	1897	101.18556
→8	1.536	2253	120.23297
→9	1.91	2533	135.76082
→10	1.537	2746	147.09171
→11	1.979	3024	162.66476
Obs 2→3	0.591	476	25.29539
→4	0.714	565	30.02105
→5	1.008	828	43.92615
→6	1.338	980	52.16415
→7	2.024	1453	77.47058
→8	2.087	1810	96.51799
→9	2.567	2094	112.04584
→10	2.386	2306	123.37673
→11	2.976	2588	138.94978
Obs 3→4	0.06	88	4.72565
→5	0.262	351	18.63075
→6	0.485	505	26.86875
→7	0.892	979	52.17518
→8	0.775	1336	71.22259
→9	0.968	1623	86.75045
→10	0.716	1834	98.08134
→11	0.985	2119	113.65439

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 4→5	0.202	262	13.90510
→6	0.408	416	22.14310
→7	0.808	890	47.44953
→8	0.692	1248	66.49694
→9	0.878	1534	82.02480
→10	0.629	1746	93.35569
→11	0.889	2032	108.92873
Obs 5→6	0.189	155	8.23800
→7	0.589	629	33.54443
→8	0.506	987	52.59184
→9	0.677	1275	68.11970
→10	0.475	1486	79.45059
→11	0.734	1773	95.02363
Obs 6→7	0.195	474	25.30643
→8	0.17	832	44.35384
→9	0.162	1121	59.88169
→10	0.52	1332	71.21259
→11	0.442	1620	86.78563
Obs 7→8	0.321	357	19.04741
→9	0.427	647	34.57527
→10	0.825	858	45.90616
→11	0.862	1148	61.47920
Obs 8→9	0.15	291	15.52786
→10	0.074	502	26.85875
→11	0.335	793	42.43179
Obs 9→10	0.104	211	11.33089
→11	0.229	502	26.90394
Obs 10→11	0.382	291	15.57305

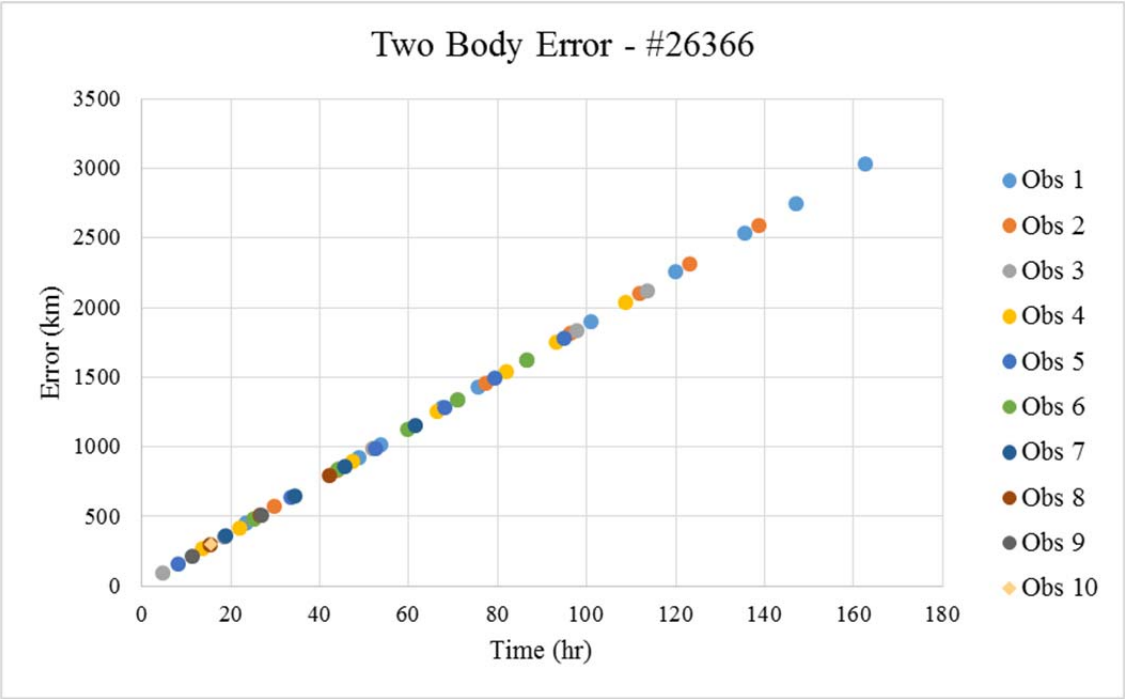

Figure 129. Error of the Two-Body Propagator Over Time–#26366

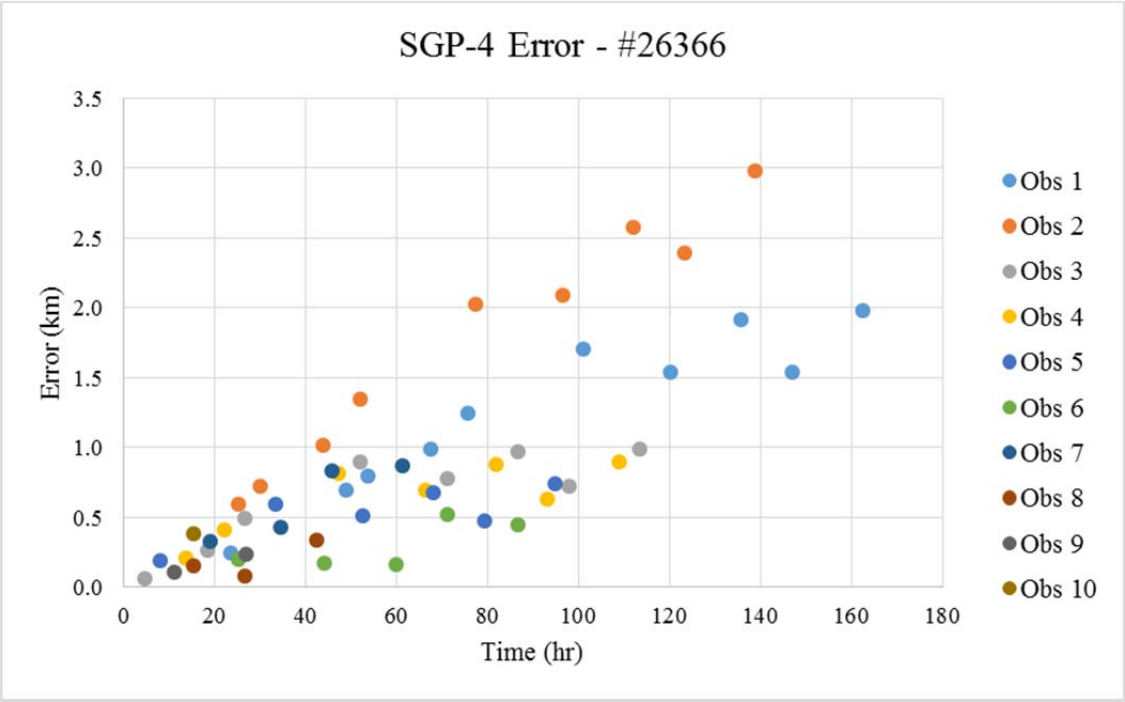

Figure 130. Error of the SGP-4 Propagator Over Time–#26366

NNN. CATALOG NUMBER 26562–PEGASUS ROCKET BODY

This ephemeris data represents one of three samples for inclinations 0–10 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 196. Two-Line Element for #26562 30NOV–7DEC15

Obs	TLE
1	1 26562U 00061B 15333.96175230 +.00002888 +00000-0 +12746-3 0 9995
	2 26562 001.9604 259.9140 0017961 265.3553 094.4437 15.07389951062373
2	1 26562U 00061B 15335.15257040 .00003059 00000-0 13837-3 0 9991
	2 26562 1.9610 250.9453 0017847 283.1334 76.6717 15.07395672830076
3	1 26562U 00061B 15336.21107556 .00003102 00000-0 14110-3 0 9999
	2 26562 1.9610 242.9761 0017833 298.8059 61.0194 15.07400332830236
4	1 26562U 00061B 15337.33573725 .00002733 00000-0 11755-3 0 9999
	2 26562 1.9611 234.5104 0017880 315.5201 44.3407 15.07403775830407
5	1 26562U 00061B 15339.12196308 .00002347 00000-0 92951-4 0 9995
	2 26562 1.9608 221.0623 0017611 342.1266 17.8157 15.07408809830678
6	1 26562U 00061B 15340.04815259 +.00002861 +00000-0 +12576-3 0 9996
	2 26562 001.9607 214.0896 0017571 356.0768 003.9136 15.07413471063297
7	1 26562U 00061B 15341.10665053 .00003111 00000-0 14168-3 0 9997
	2 26562 1.9605 206.1194 0017542 12.4768 347.5708 15.07419700830979

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 197. Ephemeris Data Derived From TLEs for #26562

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	29-Nov	23 : 4 : 55.399	15.0739	0.0017961	1.9604	265.3553	259.9140	94.4437
2	1-Dec	3 : 39 : 42.083	15.0740	17847	1.9610	283.1334	250.9453	76.6717
3	2-Dec	5 : 3 : 56.928	15.0740	17833	1.9610	298.8059	242.9761	61.0194
4	3-Dec	8 : 3 : 27.698	15.0740	17880	1.9611	315.5201	234.5104	44.3407
5	5-Dec	2 : 55 : 37.610	15.0741	17611	1.9608	342.1266	221.0623	17.8157
6	6-Dec	1 : 9 : 20.384	15.0741	17571	1.9607	356.0768	214.0896	3.9136
7	7-Dec	2 : 33 : 34.606	15.0742	17542	1.9605	12.4768	206.1194	347.5708

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 198. Error of Propagated Ephemeris for #26562

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.441	1079	28.57963
→3	0.978	2035	53.98376
→4	1.417	3040	80.97564
→5	1.27	4603	123.84506
→6	0.984	N/A	146.07361
→7	1.426	N/A	171.47756
Obs 2→3	0.131	957	25.40412
→4	0.471	1970	52.39600
→5	2.373	3556	95.26542
→6	3.835	4362	117.49397
→7	4.704	5266	142.89792
Obs 3→4	0.468	1018	26.99188
→5	2.628	2624	69.86130
→6	4.254	3445	92.08985
→7	5.336	4370	117.49380
Obs 4→5	0.525	1618	42.86942
→6	0.859	2451	65.09797
→7	0.468	3394	90.50192
Obs 5→6	0.356	838	22.22855
→7	2.217	1795	47.63250
Obs 6→7	0.696	960	25.40395

Figure 131. Error of the Two-Body Propagator Over Time–#26562

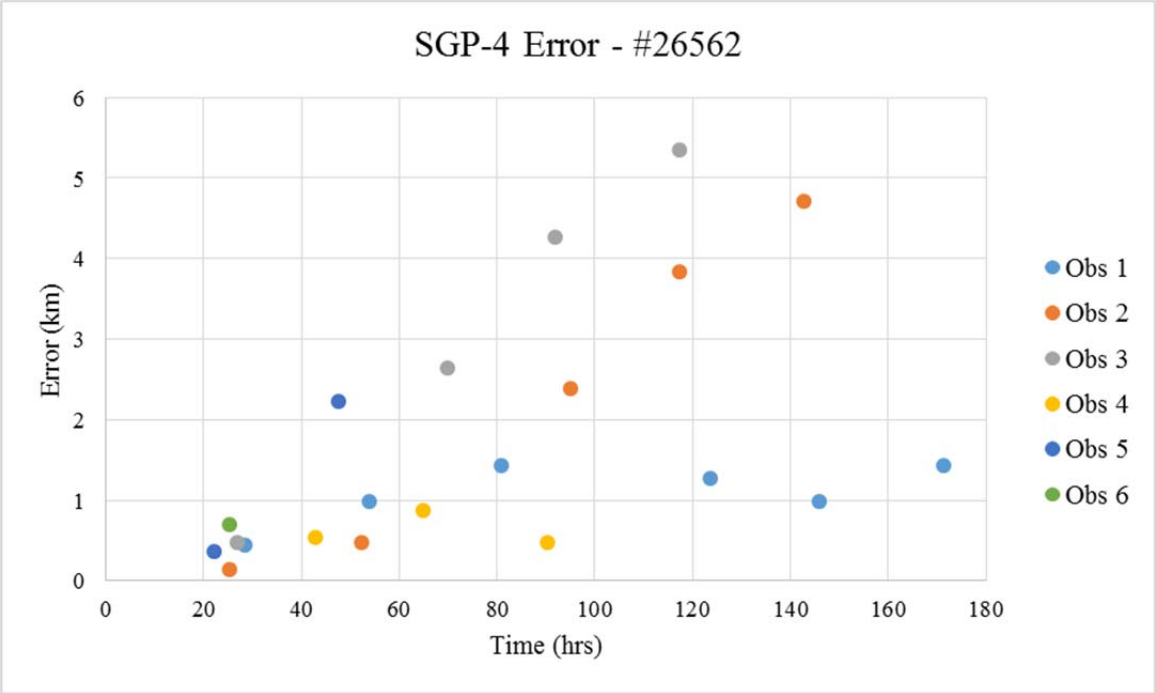

Figure 132. Error of the SGP-4 Propagator Over Time–#26562

OOO. CATALOG NUMBER 27391–GRACE 1

This ephemeris data represents one of three samples for semi-major axes 6700–6800 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 199. Two-Line Element for #27391 30NOV–7DEC15

Obs	TLE
1	1 27391U 02012A 15334.95342789 +.00014716 +00000-0 +15397-3 0 9997
	2 27391 088.9980 042.3929 0007609 160.6906 322.5859 15.64273855087785
2	1 27391U 02012A 15335.20420433 .00014180 00000-0 14831-3 0 9996
	2 27391 88.9980 42.3572 0007648 159.8074 294.6711 15.64281219768873
3	1 27391U 02012A 15335.91176258 +.00014280 +00000-0 +14923-3 0 9990
	2 27391 088.9979 042.2561 0007807 157.2836 318.8922 15.64300918087935
4	1 27391U 02012A 15336.47753671 .00014342 00000-0 14978-3 0 9991
	2 27391 88.9978 42.1756 0007922 155.3614 264.6735 15.64316098769078
5	1 27391U 02012A 15336.93721355 +.00013052 +00000-0 +13622-3 0 9998
	2 27391 088.9980 042.1101 0008014 153.8531 333.0078 15.64327093088093
6	1 27391U 02012A 15337.82794562 .00011404 00000-0 11886-3 0 9996
	2 27391 88.9981 41.9832 0008196 150.8439 308.6590 15.64349328769286
7	1 27391U 02012A 15337.95999155 +.00010885 +00000-0 +11342-3 0 9994
	2 27391 088.9982 041.9643 0008228 150.4392 332.1653 15.64351869088253
8	1 27391U 02012A 15338.85525380 .00011216 00000-0 11678-3 0 9990
	2 27391 88.9983 41.8368 0008398 147.6829 333.1309 15.64372417769446
9	1 27391U 02012A 15338.91959782 +.00010390 +00000-0 +10815-3 0 9998
	2 27391 088.9983 041.8277 0008407 147.4854 335.4357 15.64372825088403
10	1 27391U 02012A 15339.87850318 .00012828 00000-0 13347-3 0 9990
	2 27391 88.9984 41.6912 0008560 144.1994 335.1694 15.64397629769605
11	1 27391U 02012A 15339.94297650 +.00013096 +00000-0 +13626-3 0 9990
	2 27391 088.9984 041.6820 0008566 144.0036 338.2049 15.64399209088568
12	1 27391U 02012A 15340.96685499 .00015806 00000-0 16430-3 0 9993
	2 27391 88.9984 41.5363 0008732 140.8357 343.5762 15.64430034769776

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 200. Ephemeris Data Derived From TLEs for #27391

Obs	Day	Time					MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22	:	52	:	56.170	15.6427	0.0007609	88.9980	160.6906	42.3929	322.5859
2	1-Dec	4	:	54	:	3.254	15.6428	7648	88.9980	159.8074	42.3572	294.6711
3	1-Dec	21	:	52	:	56.287	15.6430	7807	88.9979	157.2836	42.2561	318.8922
4	2-Dec	11	:	27	:	39.172	15.6432	7922	88.9978	155.3614	42.1756	264.6735
5	2-Dec	22	:	29	:	35.251	15.6433	8014	88.9980	153.8531	42.1101	333.0078
6	3-Dec	19	:	52	:	14.502	15.6435	8196	88.9981	150.8439	41.9832	308.6590
7	3-Dec	23	:	2	:	23.270	15.6435	8228	88.9982	150.4392	41.9643	332.1653
8	4-Dec	20	:	31	:	33.928	15.6437	8398	88.9983	147.6829	41.8368	333.1309
9	4-Dec	22	:	4	:	13.252	15.6437	8407	88.9983	147.4854	41.8277	335.4357
10	5-Dec	21	:	5	:	2.675	15.6440	8560	88.9984	144.1994	41.6912	335.1694
11	5-Dec	22	:	37	:	53.170	15.6440	8566	88.9984	144.0036	41.6820	338.2049
12	6-Dec	23	:	12	:	16.271	15.6443	8732	88.9984	140.8357	41.5363	343.5762

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 201. Error of Propagated Ephemeris for #27391

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.0167	114	6.01863
→3	0.432	446	23.00003
→4	1.167	709	36.57861
→5	1.936	919	47.61086
→6	4.361	1319	68.98843
→7	4.68	1377	72.15753
→8	9.78	1769	93.64382
→9	10.178	1797	95.18808
→10	18.213	2206	118.20181
→11	18.917	2233	119.74917
→12	28.513	2654	144.32225
Obs 2→3	0.308	336	16.98140
→4	0.793	601	30.55998
→5	1.253	813	41.59222
→6	2.78	1217	62.96979
→7	2.948	1276	66.13889
→8	6.736	1672	87.62519
→9	7.026	1700	89.16944
→10	13.217	2113	112.18317
→11	13.782	2140	113.73053
→12	20.914	2567	138.30362
Obs 3→4	0.415	270	13.57858
→5	0.889	486	24.61082
→6	2.357	898	45.98839
→7	2.575	958	49.15750
→8	6.421	1363	70.64379
→9	6.728	1391	72.18805
→10	13.051	1813	95.20177
→11	13.627	1842	96.74913
→12	21.005	2279	121.32222
Obs 4→5	0.309	220	11.03224
→6	1.436	640	32.40981
→7	1.639	701	35.57892
→8	5.213	1114	57.06521
4→9	5.508	1144	58.60947
→10	11.581	1575	81.62320
→11	12.142	1604	83.17055
→12	19.319	2050	107.74364
Obs 5→6	0.142	424	21.37757
→7	0.197	486	24.54667
→8	1.145	903	46.03297
→9	1.249	932	47.57722
→10	3.847	1368	70.59095
→11	4.14	1397	72.13831
→12	6.427	1849	96.71139
Obs 6→7	0.059	63	3.16910
→8	0.187	488	24.65540
→9	0.183	518	26.19965
→10	0.309	963	49.21338
→11	0.379	993	50.76074
→12	1.578	1455	75.33382
Obs 7→8	0.135	425	21.48629
→9	0.181	455	23.03055
→10	0.875	900	46.04428
→11	0.864	930	47.59164
→12	4.076	1392	72.16472
Obs 8→9	0.007	31	1.54426
→10	0.123	485	24.55799
→11	0.087	515	26.10534
→12	2.293	987	50.67843
Obs 9→10	0.834	454	23.01373
→11	0.846	484	24.56109
→12	4.645	956	49.13417
Obs 10→11	0.123	31	1.54736
→12	0.295	516	26.12044
Obs 11→12	0.329	516	24.57308

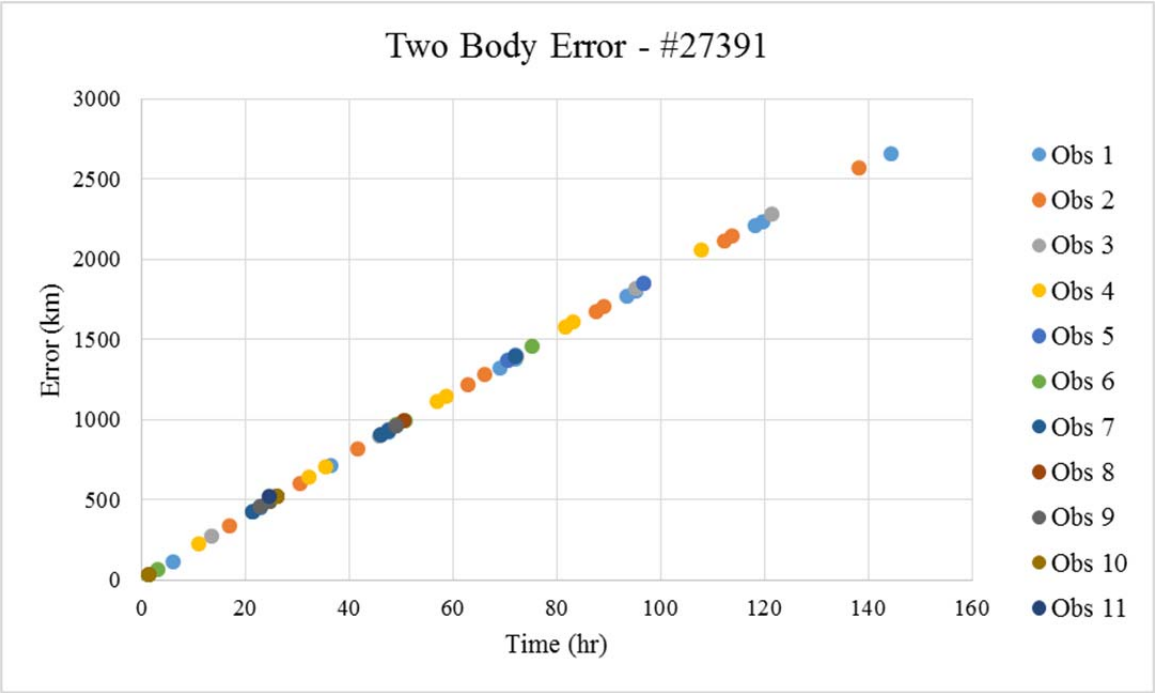

Figure 133. Error of the Two-Body Propagator Over Time–#27391

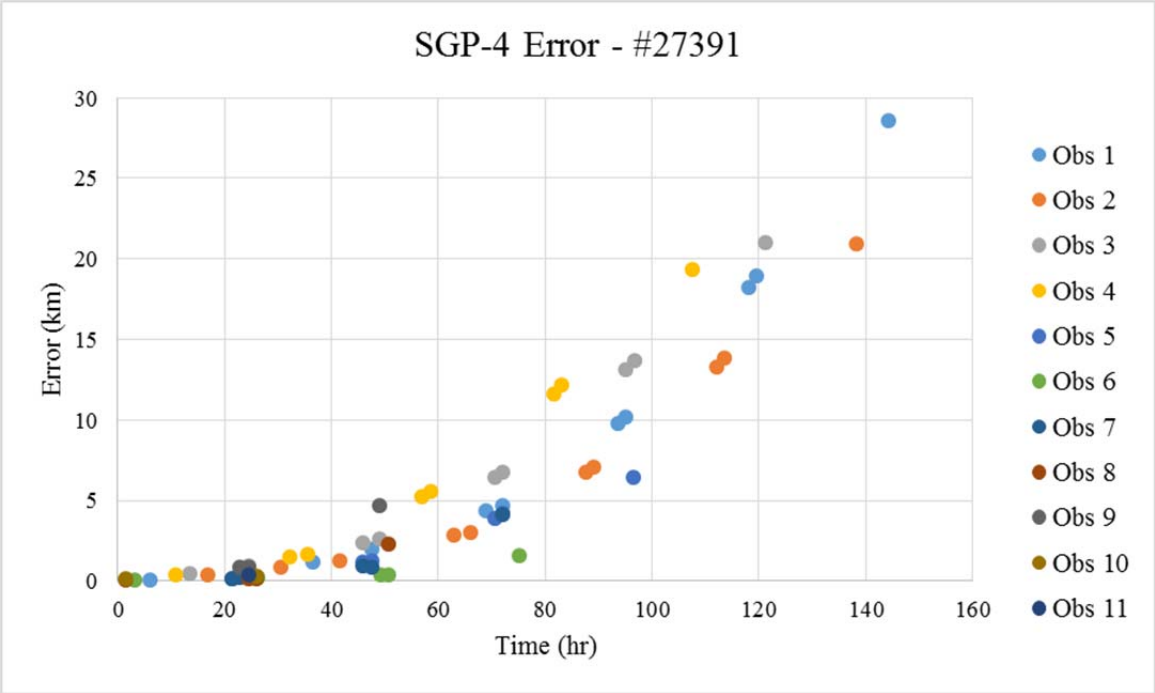

Figure 134. Error of the SGP-4 Propagator Over Time–#27391

PPP. CATALOG NUMBER 27392–GRACE 2

This ephemeris data represents one of three samples for semi-major axes 6700–6800 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 202. Two-Line Element for #27392 30NOV–7DEC15

Obs	TLEs
1	1 27392U 02012B 15334.61137301 +.00017128 +00000-0 +17903-3 0 9998
	2 27392 088.9985 042.5052 0007565 161.9110 198.2430 15.64305262768712
2	1 27392U 02012B 15335.31506647 .00013971 00000-0 14588-3 0 9997
	2 27392 88.9984 42.4049 0007709 159.3422 200.8161 15.64322560768882
3	1 27392U 02012B 15335.69889576 +.00013755 +00000-0 +14355-3 0 9995
	2 27392 088.9986 042.3504 0007776 158.0677 202.0926 15.64333178768881
4	1 27392U 02012B 15336.72243524 .00010697 00000-0 11149-3 0 9997
	2 27392 88.9987 42.2047 0007949 154.8372 205.3286 15.64347835769107
5	1 27392U 02012B 15337.17023478 .00008615 00000-0 89685-4 0 9999
	2 27392 88.9990 42.1414 0008297 151.9287 208.2431 15.64348457769170
6	1 27392U 02012B 15339.15331236 .00010295 00000-0 10712-3 0 9994
	2 27392 88.9991 41.8585 0008438 146.5849 213.5955 15.64380076769484
7	1 27392U 02012B 15339.72903389 +.00013165 +00000-0 +13699-3 0 9997
	2 27392 088.9990 041.7765 0008525 144.5183 215.6656 15.64396453769519
8	1 27392U 02012B 15340.17681354 .00013651 00000-0 14199-3 0 9999
	2 27392 88.9990 41.7128 0008594 143.0868 217.0994 15.64408087769644
9	1 27392U 02012B 15340.68855728 +.00014869 +00000-0 +15459-3 0 9995
	2 27392 088.9990 041.6401 0008681 141.5346 218.6544 15.64423169769666
10	1 27392U 02012B 15341.20029575 .00016061 00000-0 16689-3 0 9999
	2 27392 88.9990 41.5673 0008760 139.9381 220.2536 15.64439494769808

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 203. Ephemeris Data Derived From TLEs for #27392

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	14 : 40 : 22.628	15.6431	0.0007565	88.9985	161.9110	42.5052	198.2430
2	1-Dec	7 : 33 : 41.743	15.6432	7709	88.9984	159.3422	42.4049	200.8161
3	1-Dec	16 : 46 : 24.594	15.6433	7776	88.9986	158.0677	42.3504	202.0926
4	2-Dec	17 : 20 : 18.405	15.6435	7949	88.9987	154.8372	42.2047	205.3286
5	3-Dec	4 : 5 : 8.285	15.6435	8297	88.9990	151.9287	42.1414	208.2431
6	5-Dec	3 : 40 : 46.188	15.6438	8438	88.9991	146.5849	41.8585	213.5955
7	5-Dec	17 : 29 : 48.528	15.6440	8525	88.9990	144.5183	41.7765	215.6656
8	6-Dec	4 : 14 : 36.690	15.6441	8594	88.9990	143.0868	41.7128	217.0994
9	6-Dec	16 : 31 : 31.349	15.6442	8681	88.9990	141.5346	41.6401	218.6544
10	7-Dec	4 : 48 : 25.553	15.6444	8760	88.9990	139.9381	41.5673	220.2536

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 204. Error of Propagated Ephemeris for #27392

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	1.341	341	16.88864
→3	2.792	521	26.10055
→4	13.55	1014	50.66549
→5	23.728	1205	61.41268
→6	80.753	2106	109.00654
→7	100.973	2359	122.82386
→8	117.6	2552	133.57057
→9	137.205	2770	145.85242
→10	157.159	2984	158.13415
Obs 2→3	0.157	183	9.21190
→4	5.509	668	33.77685
→5	12.436	881	44.52404
→6	48.582	1796	92.11790
→7	60.745	2054	105.93522
→8	70.478	2251	116.68193
→9	81.541	2473	128.96378
→10	92.239	2691	141.24550
Obs 3→4	5.222	489	24.56495
→5	12.023	704	35.31214
→6	47.18	1629	82.90600
→7	58.915	1889	96.72332
→8	68.269	2089	107.47003
→9	78.854	2313	119.75188
→10	89.024	2534	132.03360

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 4→5	3.987	218	10.74719
→6	20.417	1162	58.34105
→7	24.79	1429	72.15837
→8	27.811	1633	82.90508
→9	30.52	1863	95.18693
→10	32.127	2089	107.46865
Obs 5→6	5.439	944	47.59386
→7	5.314	1211	61.41118
→8	4.429	1415	72.15789
→9	2.259	1646	84.43974
→10	1.606	1872	96.72146
Obs 6→7	0.496	274	13.81732
→8	1.356	485	24.56403
→9	3.163	724	36.84588
→10	6.165	958	49.12760
Obs 7→8	0.253	214	10.74671
→9	0.327	457	23.02856
→10	0.284	696	35.31028
Obs 8→9	0.107	245	12.28185
→10	0.331	486	24.56357
Obs 9→10	0.067	243	12.28172

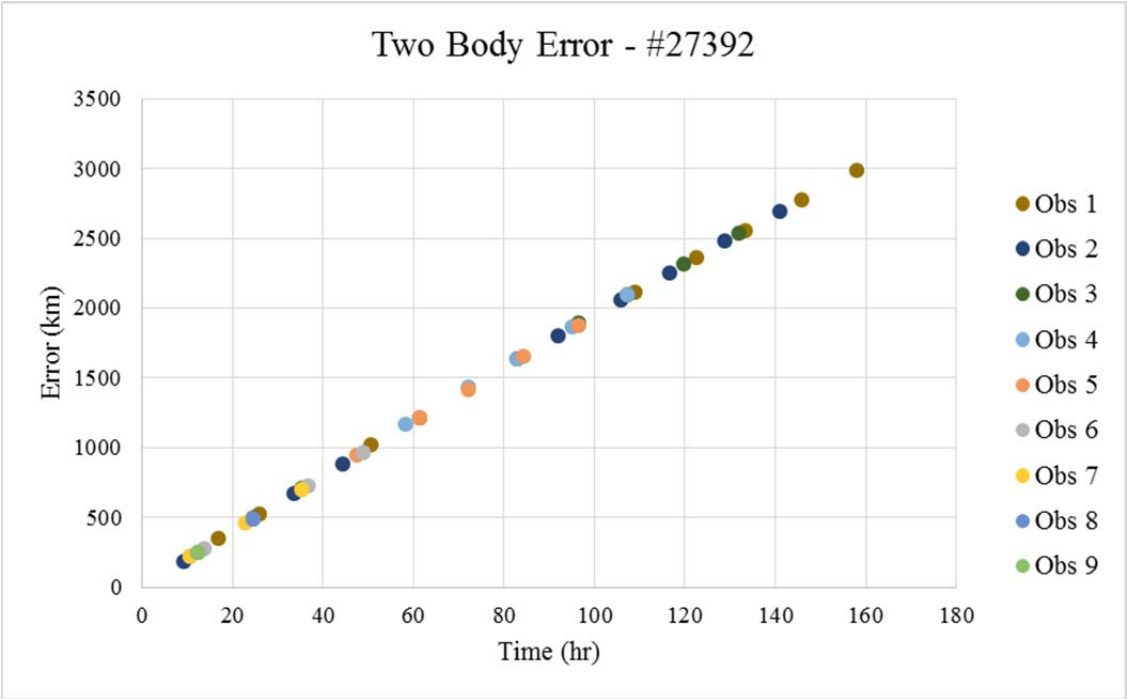

Figure 135. Error of the Two-Body Propagator Over Time–#27392

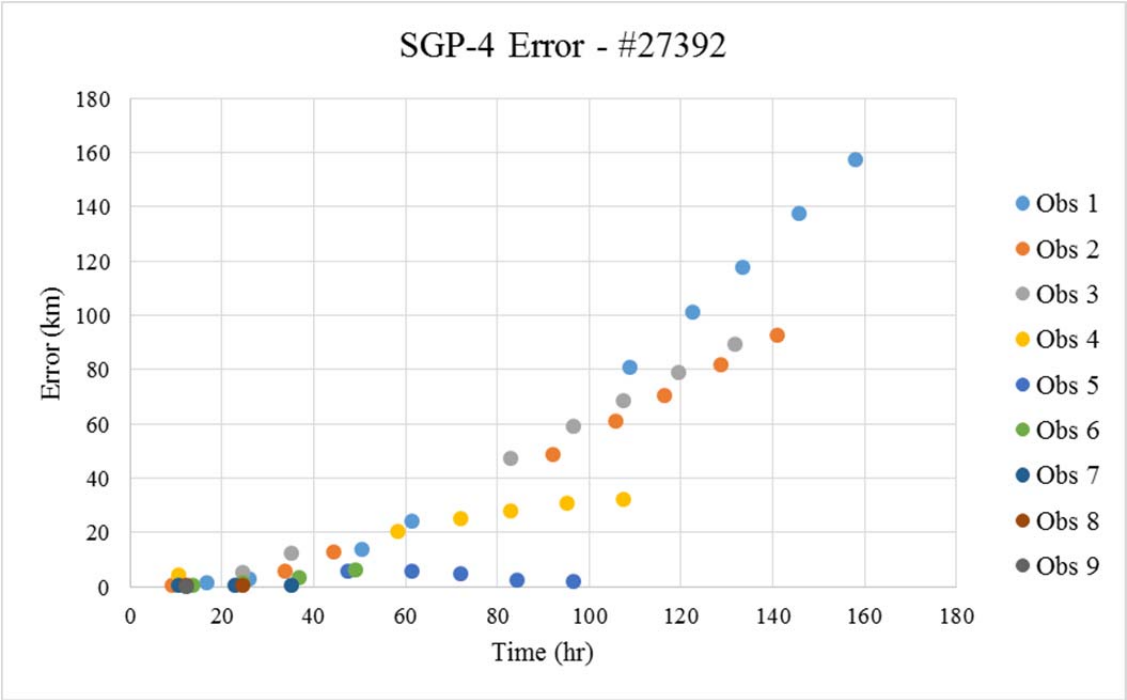

Figure 136. Error of the SGP-4 Propagator Over Time–#27392

QQQ. CATALOG NUMBER 27606–LATINSAT B

This ephemeris data represents one of three samples for inclinations 60–70 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 205. Two-Line Element for #27606 30NOV–7DEC15

Obs	TLE
1	1 27606U 02058B 15335.76825804 +.00000446 +00000-0 +88470-4 0 9998 2 27606 064.5557 097.2456 0092353 260.2212 098.8450 14.71802879694926
2	1 27606U 02058B 15336.44773255 .00000406 00000-0 82526-4 0 9998 2 27606 64.5559 95.1805 0092341 260.0868 98.9800 14.71803462695059
3	1 27606U 02058B 15336.78746978 +.00000387 +00000-0 +79662-4 0 9992 2 27606 064.5559 094.1480 0092334 260.0226 099.0445 14.71803703695074
4	1 27606U 02058B 15337.73873346 .00000355 00000-0 74975-4 0 9995 2 27606 64.5561 91.2570 0092322 259.8399 99.2278 14.71804566695242
5	1 27606U 02058B 15339.16562783 .00000285 00000-0 64524-4 0 9995 2 27606 64.5563 86.9204 0092289 259.5526 99.5164 14.71805703695454
6	1 27606U 02058B 15339.91304804 +.00000351 +00000-0 +74339-4 0 9995 2 27606 064.5564 084.6488 0092273 259.4039 099.6658 14.71806850695537
7	1 27606U 02058B 15340.52457342 .00000385 00000-0 79491-4 0 9991 2 27606 64.5564 82.7903 0092267 259.2807 99.7895 14.71807651695659
8	1 27606U 02058B 15340.72841514 +.00000418 +00000-0 +84361-4 0 9990 2 27606 064.5564 082.1708 0092262 259.2424 099.8280 14.71808029695655
9	1 27606U 02058B 15341.67967620 .00000411 00000-0 83260-4 0 9992 2 27606 64.5565 79.2797 0092244 259.0520 100.0192 14.71808959695824

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 206. Ephemeris Data Derived From TLEs for #27606

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	18 : 26 : 17.495	14.7180	0.0092353	64.5557	260.2212	97.2456	98.8450
2	2-Dec	10 : 44 : 44.092	14.7180	92341	64.5559	260.0868	95.1805	98.9800
3	2-Dec	18 : 53 : 57.389	14.7180	92334	64.5559	260.0226	94.1480	99.0445
4	3-Dec	17 : 43 : 46.571	14.7180	92322	64.5561	259.8399	91.2570	99.2278
5	5-Dec	3 : 58 : 30.245	14.7181	92289	64.5563	259.5526	86.9204	99.5164
6	5-Dec	21 : 54 : 47.351	14.7181	92273	64.5564	259.4039	84.6488	99.6658
7	6-Dec	12 : 35 : 23.143	14.7181	92267	64.5564	259.2807	82.7903	99.7895
8	6-Dec	17 : 28 : 55.068	14.7181	92262	64.5564	259.2424	82.1708	99.8280
9	7-Dec	16 : 18 : 44.024	14.7181	92244	64.5565	259.0520	79.2797	100.0192

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 207. Error of Propagated Ephemeris for #27606

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.114	264	16.30739
→3	0.213	396	24.46108
→4	0.487	765	47.29141
→5	1.001	1318	81.53687
→6	1.290	1605	99.47496
→7	1.542	1842	114.15157
→8	1.656	1919	119.04377
→9	2.154	2284	141.87404
Obs 2→3	0.079	132	8.15369
→4	0.261	501	30.98402
→5	0.572	1055	65.22949
→6	0.728	1343	83.16757
→7	0.859	1580	97.84418
→8	0.921	1657	102.73638
→9	1.185	2023	125.56665
Obs 3→4	0.149	369	22.83033
→5	0.382	923	57.07579
→6	0.496	1211	75.01388
→7	0.587	1449	89.69049
→8	0.625	1526	94.58269
→9	0.796	1892	117.41295
Obs 4→5	0.210	554	34.24546
→6	0.336	843	52.18355
→7	0.434	1080	66.86016
→8	0.464	1158	71.75236
→9	0.618	1525	94.58263
Obs 5→6	0.224	291	17.93809
→7	0.414	530	32.61469
→8	0.483	609	37.50690
→9	0.818	979	60.33716
Obs 6→7	0.090	239	14.67661
→8	0.124	318	19.56881
→9	0.271	688	42.39908
Obs 7→8	0.032	79	4.89220
→9	0.194	450	27.72247
Obs 8→9	0.216	371	22.83027

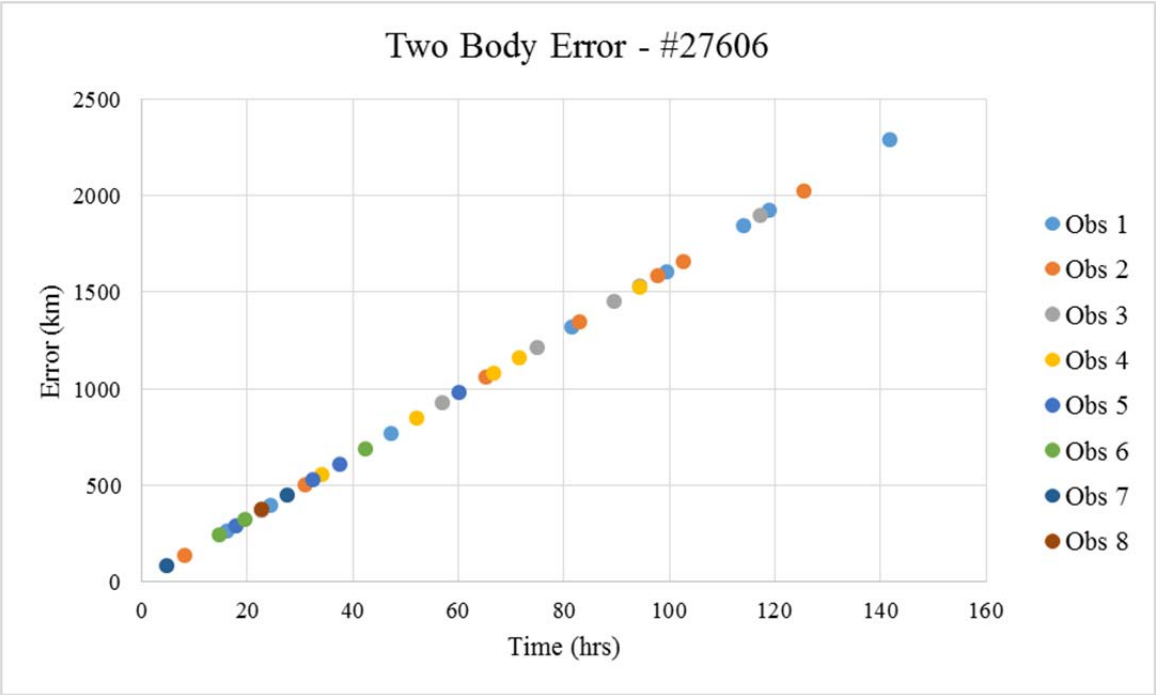

Figure 137. Error of the Two-Body Propagator Over Time–#27606

Figure 138. Error of the SGP-4 Propagator Over Time–#27606

RRR. CATALOG NUMBER 28230–GP-B

This ephemeris data represents one of three samples for semi-major axes 7000–7100 km in the experiment to determine the effect of the altitude on propagator accuracy and one of three samples for inclinations 80–90 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 208. Two-Line Element for #28230 30NOV–7DEC15

Obs	TLE
1	1 28230U 04014A 15334.88158010 +.00000517 +00000-0 +68977-4 0 9995 2 28230 089.8658 132.0365 0002907 077.1265 283.0282 14.78299739082922
2	1 28230U 04014A 15335.22003386 .00000458 00000-0 60862-4 0 9998 2 28230 89.8658 132.0310 0002898 77.0245 283.1301 14.78299674625775
3	1 28230U 04014A 15335.89694088 +.00000472 +00000-0 +62861-4 0 9993 2 28230 089.8659 132.0197 0002876 076.9492 283.2052 14.78300362083079
4	1 28230U 04014A 15336.50615696 .00000449 00000-0 59644-4 0 9999 2 28230 89.8659 132.0097 0002855 76.7404 283.4137 14.78300762625966
5	1 28230U 04014A 15336.91230099 +.00000430 +00000-0 +57039-4 0 9990 2 28230 089.8660 132.0029 0002836 076.5967 283.5571 14.78300972083227
6	1 28230U 04014A 15337.79227930 .00000421 00000-0 55729-4 0 9991 2 28230 89.8660 131.9884 0002806 76.3825 283.7709 14.78301644626159
7	1 28230U 04014A 15337.85996994 +.00000415 +00000-0 +55004-4 0 9990 2 28230 089.8660 131.9873 0002800 076.3294 283.8240 14.78301671083362
8	1 28230U 04014A 15338.87532897 .00000392 00000-0 51795-4 0 9998 2 28230 89.8661 131.9705 0002753 75.9351 284.2178 14.78302400626317
9	1 28230U 04014A 15338.94301959 +.00000361 +00000-0 +47473-4 0 9993 2 28230 089.8661 131.9694 0002751 075.8665 284.2863 14.78302285083521
10	1 28230U 04014A 15339.89068736 +.00000427 +00000-0 +56549-4 0 9998 2 28230 089.8662 131.9538 0002715 075.6891 284.4633 14.78303437083660
11	1 28230U 04014A 15340.16144951 .00000428 00000-0 56759-4 0 9998 2 28230 89.8662 131.9493 0002706 75.5615 284.5908 14.78303646626507
12	1 28230U 04014A 15340.97373540 +.00000511 +00000-0 +68221-4 0 9995 2 28230 089.8663 131.9359 0002664 075.2146 284.9372 14.78304821083825
13	1 28230U 04014A 15341.17680680 .00000521 00000-0 69612-4 0 9990 2 28230 89.8663 131.9326 0002658 75.1225 285.0291 14.78305047626656

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 209. Ephemeris Data Derived From TLEs for #28230

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 9 : 28.521	14.7830	0.0002907	89.8658	77.1265	132.0365	283.0282
2	1-Dec	5 : 16 : 50.926	14.7830	2898	89.8658	77.0245	132.0310	283.1301
3	1-Dec	21 : 31 : 35.692	14.7830	2876	89.8659	76.9492	132.0197	283.2052
4	2-Dec	12 : 8 : 51.961	14.7830	2855	89.8659	76.7404	132.0097	283.4137
5	2-Dec	21 : 53 : 42.806	14.7830	2836	89.8660	76.5967	132.0029	283.5571
6	3-Dec	19 : 0 : 52.932	14.7830	2806	89.8660	76.3825	131.9884	283.7709
7	3-Dec	20 : 38 : 21.403	14.7830	2800	89.8660	76.3294	131.9873	283.8240
8	4-Dec	21 : 0 : 28.423	14.7830	2753	89.8661	75.9351	131.9705	284.2178
9	4-Dec	22 : 37 : 56.893	14.7830	2751	89.8661	75.8665	131.9694	284.2863
10	5-Dec	21 : 22 : 35.388	14.7830	2715	89.8662	75.6891	131.9538	284.4633
11	6-Dec	3 : 52 : 29.238	14.7830	2706	89.8662	75.5615	131.9493	284.5908
12	6-Dec	23 : 22 : 10.739	14.7830	2664	89.8663	75.2146	131.9359	284.9372
13	7-Dec	4 : 14 : 36.108	14.7831	2658	89.8663	75.1225	131.9326	285.0291

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 210. Error of Propagated Ephemeris for #28230

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.163	148	8.12289
→3	0.328	444	24.36866
→4	0.503	710	38.98984
→5	0.703	887	48.73730
→6	1.098	1270	69.85678
→7	1.156	1300	71.48136
→8	1.706	1740	95.84997
→9	1.751	1769	97.47455
→10	2.318	2178	120.21857
→11	2.509	2295	126.71687
→12	2.930	2643	146.21173
→13	3.007	2730	151.08544
Obs 2→3	0.084	296	16.24577
→4	0.159	562	30.86695
→5	0.235	739	40.61441
→6	0.392	1123	61.73389
→7	0.420	1152	63.35847
→8	0.634	1593	87.72708
→9	0.655	1622	89.35166
→10	0.860	2032	112.09568
→11	0.934	2148	118.59398
→12	1.016	2497	138.08884
→13	1.015	2584	142.96255
Obs 3→4	0.084	266	14.62119
→5	0.188	444	24.36864
→6	0.386	827	45.48812
→7	0.417	857	47.11270
→8	0.692	1299	71.48131
→9	0.723	1328	73.10589
→10	0.989	1739	95.84992
→11	1.085	1856	102.34821
→12	1.219	2205	121.84307
→13	1.232	2293	126.71678
Obs 4→5	0.085	177	9.74746
→6	0.218	562	30.86694
→7	0.239	591	32.49151
→8	0.417	1033	56.86013
→9	0.442	1063	58.48470
→10	0.598	1474	81.22873
→11	0.655	1591	87.72702
4→12	0.696	1942	107.22188
→13	0.694	2030	112.09560
Obs 5→6	0.108	384	21.11948
→7	0.118	414	22.74405
→8	0.241	856	47.11267
→9	0.256	886	48.73725
→10	0.362	1298	71.48127
→11	0.394	1415	77.97956
→12	0.464	1766	97.47443
→13	0.492	1854	102.34814
Obs 6→7	0.009	30	1.62458
→8	0.124	472	25.99319
→9	0.134	502	27.61777
→10	0.245	915	50.36179
→11	0.273	1032	56.86009
→12	0.416	1384	76.35495
→13	0.470	1472	81.22866
Obs 7→8	0.118	443	24.36862
→9	0.123	472	25.99319
→10	0.244	885	48.73722
→11	0.272	1003	55.23551
→12	0.446	1355	74.73037
→13	0.509	1443	79.60408
Obs 8→9	0.030	30	1.62457
→10	0.159	443	24.36860
→11	0.197	560	30.86689
→12	0.476	913	50.36175
→13	0.559	1002	55.23547
Obs 9→10	0.244	413	22.74403
→11	0.305	531	29.24232
→12	0.689	884	48.73718
→13	0.800	972	53.61089
Obs 10→11	0.029	118	6.49829
→12	0.217	471	25.99315
→13	0.269	560	30.86687
Obs 11→12	0.212	353	19.49486
→13	0.265	442	24.36857
Obs 12→13	0.023	88	4.87371

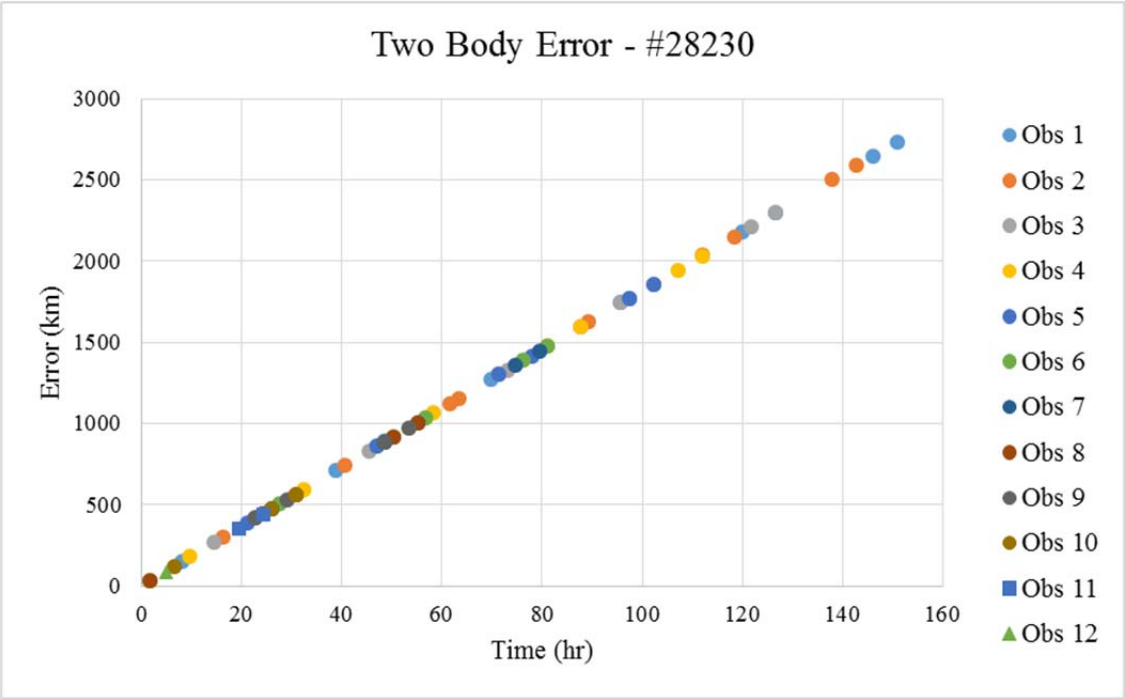

Figure 139. Error of the Two-Body Propagator Over Time–#28230

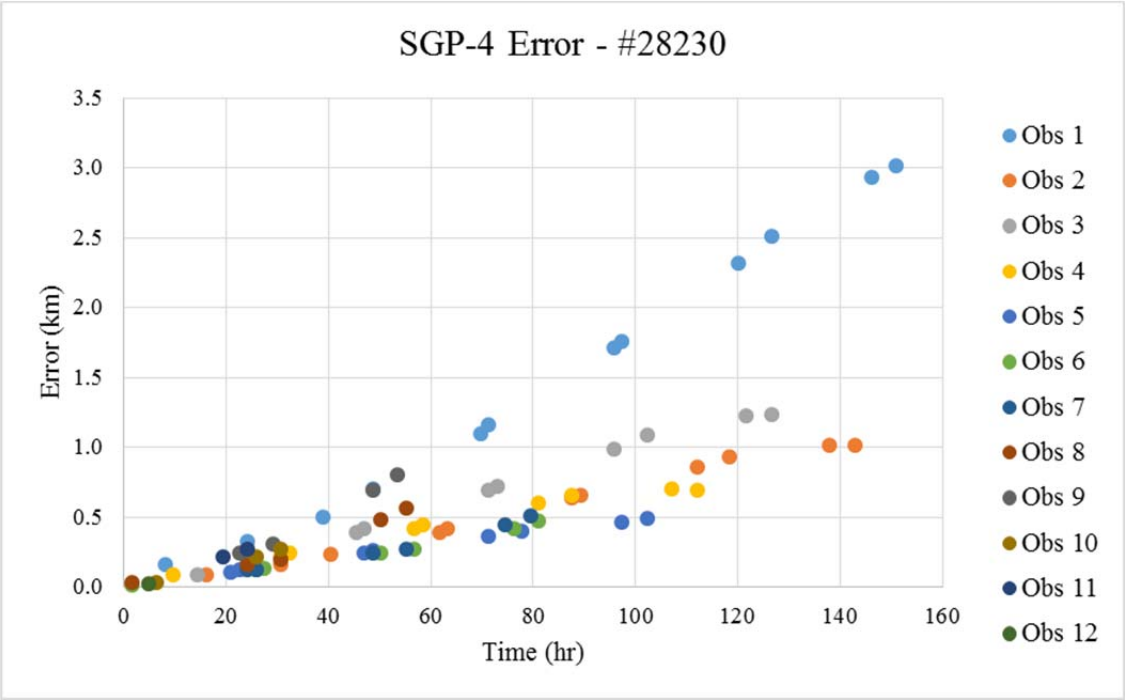

Figure 140. Error of the SGP-4 Propagator Over Time–#28230

SSS. CATALOG NUMBER 28642–DART

This ephemeris data represents one of three samples for semi-major axes 6700–6800 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 211. Two-Line Element for #28642 30NOV–7DEC15

Obs	TLE
1	1 28642U 05014A 15334.87676076 +.00061729 +00000-0 +41137-3 0 9999
	2 28642 096.5800 265.1818 0071943 105.6678 255.2540 15.71562245587225
2	1 28642U 05014A 15335.38614958 .00049900 00000-0 33247-3 0 9997
	2 28642 96.5795 265.6623 0071865 103.7522 257.1755 15.71609836587303
3	1 28642U 05014A 15335.83185101 +.00055751 +00000-0 +37043-3 0 9999
	2 28642 096.5794 266.0826 0071828 102.1434 258.7890 15.71657053587374
4	1 28642U 05014A 15336.53220843 .00058823 00000-0 38942-3 0 9992
	2 28642 96.5793 266.7429 0071742 99.5302 261.4080 15.71737452587483
5	1 28642U 05014A 15336.85054139 +.00053330 +00000-0 +35282-3 0 9992
	2 28642 096.5795 267.0431 0071697 098.4227 262.5173 15.71772866587534
6	1 28642U 05014A 15337.55084743 .00049800 00000-0 32877-3 0 9998
	2 28642 96.5796 267.7039 0071519 95.8378 265.1046 15.71848608587645
7	1 28642U 05014A 15337.86915832 +.00047750 +00000-0 +31490-3 0 9996
	2 28642 096.5797 268.0044 0071500 094.6851 266.2584 15.71880830587696
8	1 28642U 05014A 15338.82405306 .00049300 00000-0 32378-3 0 9992
	2 28642 96.5792 268.9056 0071466 91.1477 269.7977 15.71970945587848
9	1 28642U 05014A 15338.88771071 +.00045400 +00000-0 +29829-3 0 9997
	2 28642 096.5792 268.9656 0071471 090.9434 270.0021 15.71974136587852
10	1 28642U 05014A 15339.84254539 .00058255 00000-0 38055-3 0 9992
	2 28642 96.5793 269.8666 0071315 87.3932 273.5494 15.72077366588004
11	1 28642U 05014A 15339.90619895 +.00059124 +00000-0 +38609-3 0 9990
	2 28642 096.5794 269.9266 0071307 087.2238 273.7186 15.72083231588010
12	1 28642U 05014A 15340.98825471 .00069625 00000-0 45174-3 0 9991
	2 28642 96.5802 270.9478 0071032 83.2267 277.7075 15.72224041588185

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 212. Ephemeris Data Derived From TLEs for #28642

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	21 : 2 : 32.130	15.7156	0.0071943	96.5800	105.6678	265.1818	255.2540
2	1-Dec	9 : 16 : 3.324	15.7161	71865	96.5795	103.7522	265.6623	257.1755
3	1-Dec	19 : 57 : 51.927	15.7166	71828	96.5794	102.1434	266.0826	258.7890
4	2-Dec	12 : 46 : 22.808	15.7174	71742	96.5793	99.5302	266.7429	261.4080
5	2-Dec	20 : 24 : 46.776	15.7177	71697	96.5795	98.4227	267.0431	262.5173
6	3-Dec	13 : 13 : 13.218	15.7185	71519	96.5796	95.8378	267.7039	265.1046
7	3-Dec	20 : 51 : 35.279	15.7188	71500	96.5797	94.6851	268.0044	266.2584
8	4-Dec	19 : 46 : 38.184	15.7197	71466	96.5792	91.1477	268.9056	269.7977
9	4-Dec	21 : 18 : 18.205	15.7197	71471	96.5792	90.9434	268.9656	270.0021
10	5-Dec	20 : 13 : 15.922	15.7208	71315	96.5793	87.3932	269.8666	273.5494
11	5-Dec	21 : 44 : 55.589	15.7208	71307	96.5794	87.2238	269.9266	273.7186
12	6-Dec	23 : 43 : 5.207	15.7222	71032	96.5802	83.2267	270.9478	277.7075

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 213. Error of Propagated Ephemeris for #28642

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	2.377	247	12.22533
→3	6.446	455	22.92217
→4	13.77	727	39.73074
→5	18.122	893	47.37074
→6	29.094	1164	64.17808
→7	35.994	1283	71.81754
→8	63.968	1610	94.73502
→9	66.283	1630	96.26280
→10	106.489	1919	119.17883
→11	109.395	1938	120.70652
→12	158.261	2205	146.67585
Obs 2→3	0.216	210	10.69683
→4	2.634	485	27.50541
→5	4.528	652	35.14540
→6	10.979	927	51.95275
→7	13.634	1047	59.59221
→8	20.651	1379	82.50968
→9	21.035	1369	84.03747
→10	25.965	1693	106.95350
→11	26.334	1712	108.48118
→12	41.058	1985	134.45052
Obs 3→4	0.842	289	16.80858
→5	1.049	463	24.44857
→6	2.042	751	41.25591
→7	1.44	878	48.89538
→8	4.433	1228	71.81285
→9	5.071	1249	73.34063
→10	17.788	1561	96.25667
→11	18.743	1582	97.78435
→12	29.939	1875	123.75369
Obs 4→5	0.262	185	7.63999
→6	1.089	498	24.44734
→7	2.926	635	32.08680
→8	13.888	1018	55.00427

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 4→9	14.95	1042	56.53205
→10	35.248	1386	79.44809
→11	36.782	1408	80.97577
→12	59.498	1738	106.94511
Obs 5→6	0.942	323	16.80734
→7	0.663	464	24.44681
→8	2.781	860	47.36428
→9	3.178	885	48.89206
→10	11.261	1242	71.80810
→11	11.852	1265	73.33578
→12	15.042	1610	99.30512
Obs 6→7	0.28	154	7.63946
→8	1.73	594	30.55694
→9	1.89	621	32.08472
→10	6.897	1021	55.00075
→11	7.335	1047	56.52844
→12	17.695	1440	82.49777
Obs 7→8	0.844	447	22.91747
→9	0.904	475	24.44526
→10	3.557	883	47.36129
→11	3.789	909	48.88898
→12	9.352	1311	74.85831
Obs 8→9	0.048	30	1.52778
→10	0.844	466	24.44382
→11	0.868	494	25.97150
→12	8.735	928	51.94084
Obs 9→10	1.944	436	22.91603
→11	2.22	464	24.44372
→12	18.813	899	50.41306
Obs 10→11	0.209	31	1.52769
→12	1.892	514	27.49702
Obs 11→12	2.383	485	25.96934

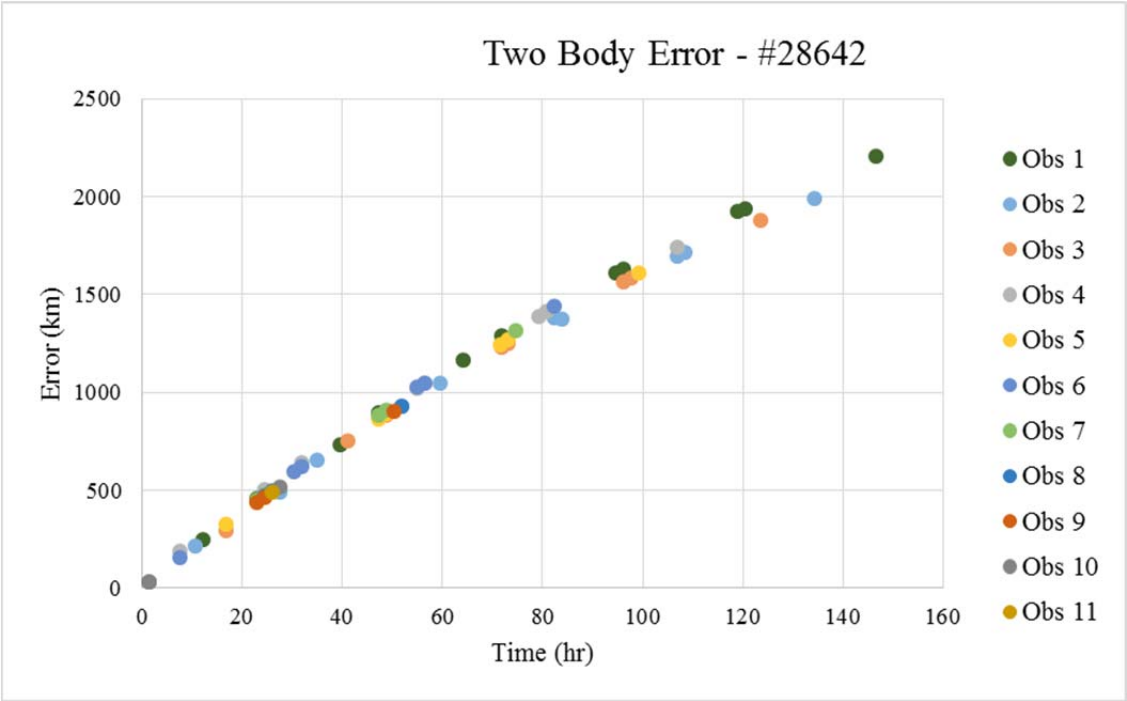

Figure 141. Error of the Two-Body Propagator Over Time–#28642

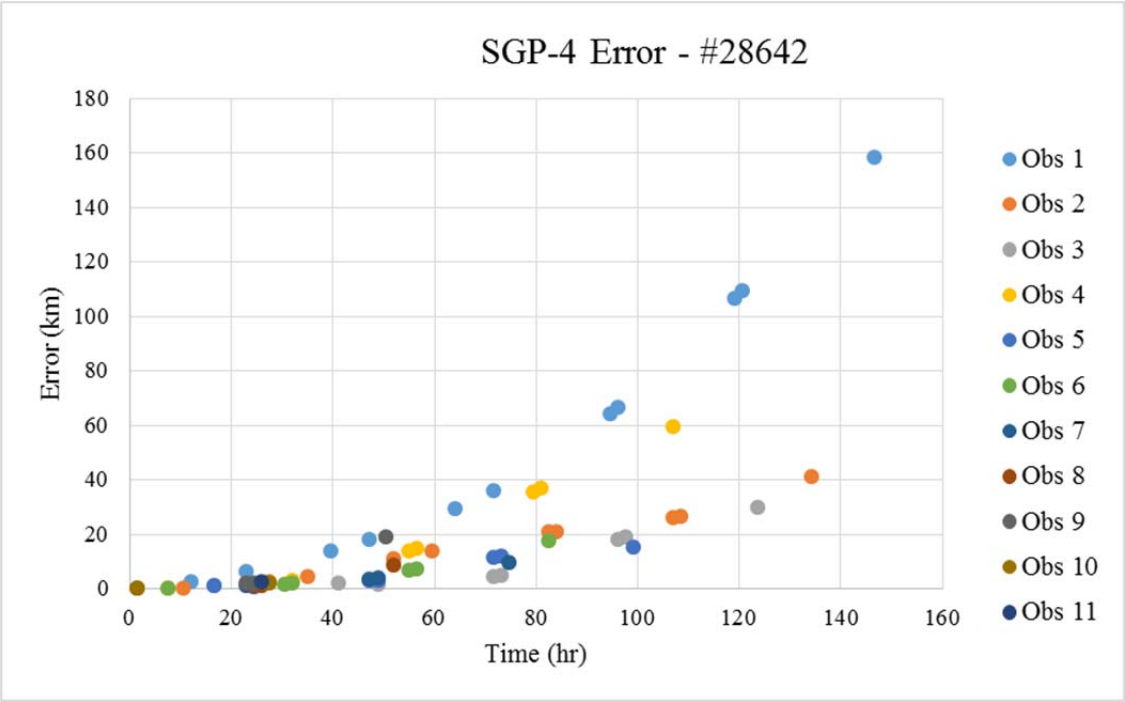

Figure 142. Error of the SGP-4 Propagator Over Time–#28642

TTT. CATALOG NUMBER 29006–TIROS 6 DEBRIS

This ephemeris data represents one of three samples for inclinations 50–60 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 214. Two-Line Element for #29006 30NOV–7DEC15

Obs	TLE
1	1 29006U 62047F 15334.07241118 +.00000108 +00000-0 +39955-4 0 9990
	2 29006 058.3096 173.9370 0015576 118.3782 241.8832 14.81003428130502
2	1 29006U 62047F 15337.98767387 .00000077 00000-0 35950-4 0 9990
	2 29006 58.3093 159.1734 0015269 121.6732 238.5800 14.81005761693234
3	1 29006U 62047F 15339.06774523 +.00000069 +00000-0 +34882-4 0 9995
	2 29006 058.3095 155.1005 0015184 122.5290 237.7221 14.81006405131240
4	1 29006U 62047F 15342.91549407 .00000126 00000-0 42212-4 0 9994
	2 29006 58.3095 140.5930 0014831 126.2779 233.9635 14.81009322693966

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 215. Ephemeris Data Derived From TLEs for #29006

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	1 : 44 : 16.326	14.8100	0.0015576	58.3096	118.3782	173.9370	241.8832
2	3-Dec	23 : 42 : 15.022	14.8101	15269	58.3093	121.6732	159.1734	238.5800
3	5-Dec	1 : 37 : 33.188	14.8101	15184	58.3095	122.5290	155.1005	237.7221
4	8-Dec	21 : 58 : 18.688	14.8101	14831	58.3095	126.2779	140.5930	233.9635

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 216. Error of Propagated Ephemeris for #29006

	Error (km)	
	SGP-4	Two Body
Obs 1→2	0.468	1558
→3	0.601	1980
→4	1.277	3463
Obs 2→3	0.15	432
→4	1.514	1959
Obs 3→4	1.456	1533

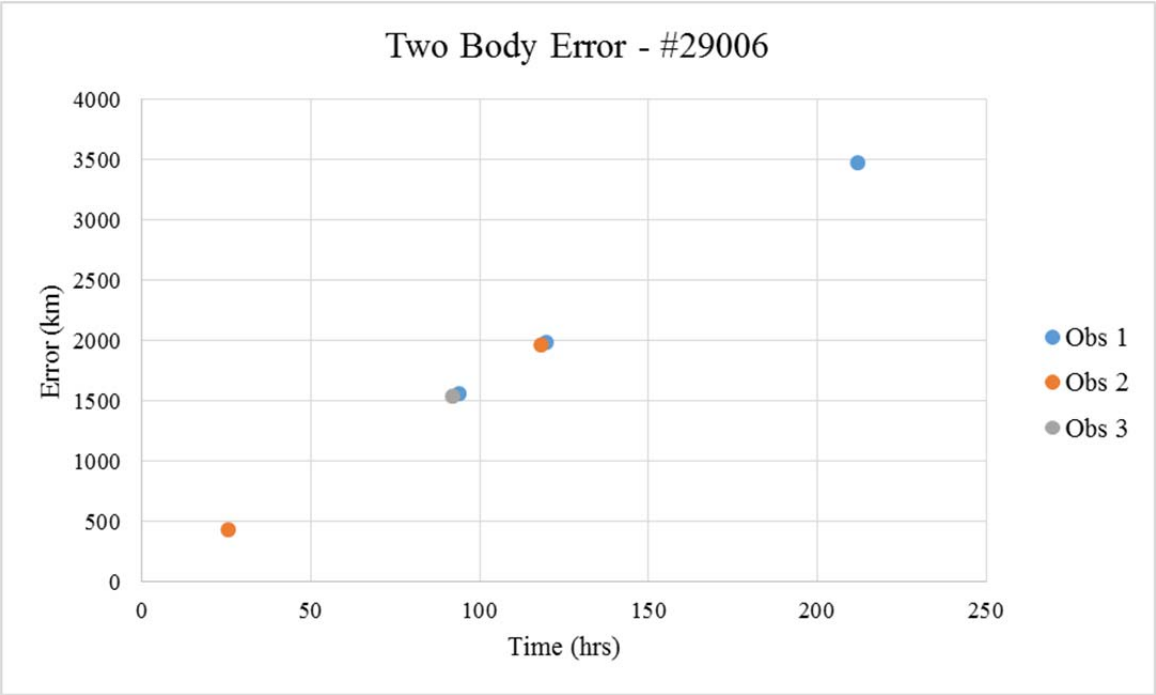

Figure 143. Error of the Two-Body Propagator Over Time–#29006

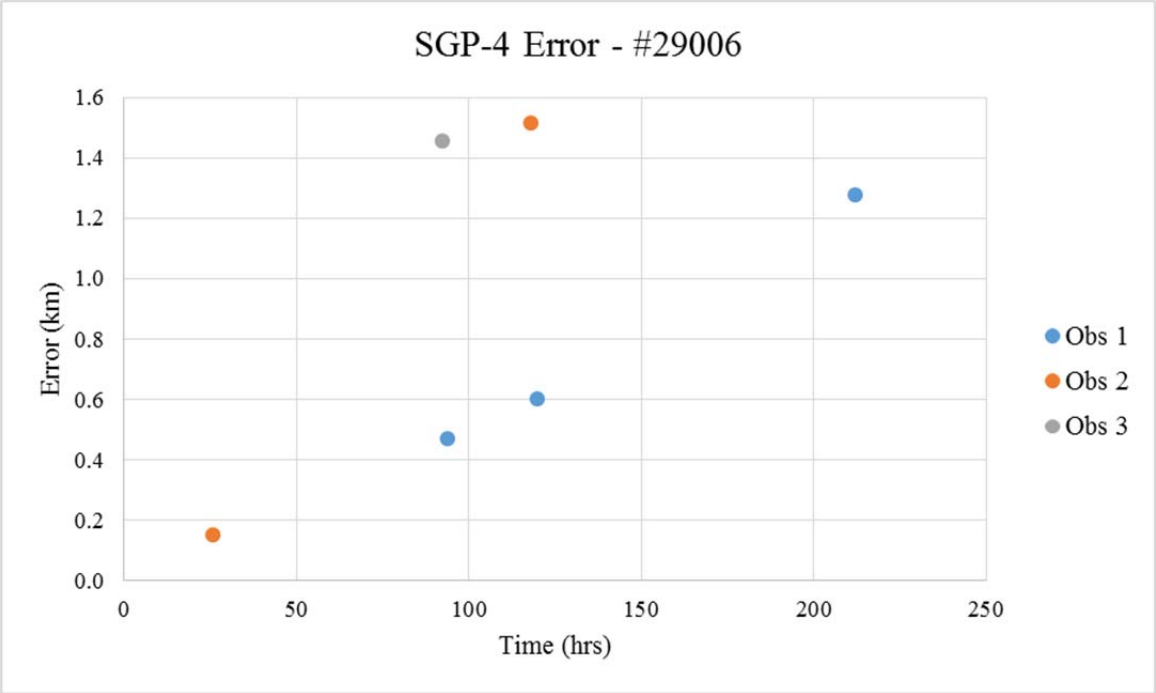

Figure 144. Error of the SGP-4 Propagator Over Time–#29006

UUU. CATALOG NUMBER 29256–SL-24 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.07-0.08 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 217. Two-Line Element for #29256 30NOV–7DEC15

Obs	TLE
1	1 29256U 06029C 15335.83242190 -.00000049 +00000-0 +19245-4 0 9996
	2 29256 064.5836 084.9338 0788881 060.7673 306.9900 13.33658732457017
2	1 29256U 06029C 15336.80722671 -.00000060 00000-0 15740-4 0 9990
	2 29256 64.5837 82.5533 0788938 60.5400 307.1992 13.33658780457183
3	1 29256U 06029C 15336.88221169 -.00000060 +00000-0 +15568-4 0 9992
	2 29256 064.5837 082.3702 0788944 060.5224 307.2154 13.33658793457152
4	1 29256U 06029C 15337.85701639 -.00000070 +00000-0 +12364-4 0 9997
	2 29256 064.5839 079.9897 0789006 060.2951 307.4246 13.33658854457281
5	1 29256U 06029C 15338.83182095 -.00000068 00000-0 13062-4 0 9998
	2 29256 64.5840 77.6091 0789057 60.0681 307.6332 13.33658997457453
6	1 29256U 06029C 15339.80662551 -.00000070 +00000-0 +12508-4 0 9993
	2 29256 064.5841 075.2286 0789115 059.8417 307.8413 13.33659115457547
7	1 29256U 06029C 15340.70644497 -.00000068 +00000-0 +12994-4 0 9999
	2 29256 064.5841 073.0311 0789164 059.6327 308.0333 13.33659221457669
8	1 29256U 06029C 15341.23133963 -.00000077 00000-0 10202-4 0 9999
	2 29256 64.5841 71.7493 0789189 59.5110 308.1449 13.33659224457775

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 218. Ephemeris Data Derived From TLEs for #29256

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	19 : 58 : 41.252	13.3366	0.0788881	64.5836	60.7673	84.9338	306.9900
2	2-Dec	19 : 22 : 24.388	13.3366	788938	64.5837	60.5400	82.5533	307.1992
3	2-Dec	21 : 10 : 23.090	13.3366	788944	64.5837	60.5224	82.3702	307.2154
4	3-Dec	20 : 34 : 6.216	13.3366	789006	64.5839	60.2951	79.9897	307.4246
5	4-Dec	19 : 57 : 49.330	13.3366	789057	64.5840	60.0681	77.6091	307.6332
6	5-Dec	19 : 21 : 32.444	13.3366	789115	64.5841	59.8417	75.2286	307.8413
7	6-Dec	16 : 57 : 16.845	13.3366	789164	64.5841	59.6327	73.0311	308.0333
8	7-Dec	5 : 33 : 7.744	13.3366	789189	64.5841	59.5110	71.7493	308.1449

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 219. Error of Propagated Ephemeris for #29256

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.092	312	23.39532
→3	0.099	336	25.19495
→4	0.187	647	48.59027
→5	0.283	961	71.98558
→6	0.391	1271	95.38089
→7	0.483	1556	116.97655
→8	0.544	1721	129.57403
Obs 2→3	0.007	24	1.79964
→4	0.088	335	25.19495
→5	0.169	649	48.59026
→6	0.244	960	71.98557
→7	0.321	1246	93.58124
→8	0.358	1412	106.17871
Obs 3→4	0.081	312	23.39531
→5	0.163	625	46.79062
→6	0.239	936	70.18593
→7	0.315	1222	91.78160
→8	0.352	1388	104.37907
Obs 4→5	0.09	313	23.39531
→6	0.163	624	46.79062
→7	0.251	911	68.38629
→8	0.29	1079	80.98376
Obs 5→6	0.081	312	23.39531
→7	0.154	599	44.99098
→8	0.191	767	57.58845
Obs 6→7	0.078	288	21.59567
→8	0.116	455	34.19314
Obs 7→8	0.045	168	12.59747

Figure 145. Error of the Two-Body Propagator Over Time–#29256

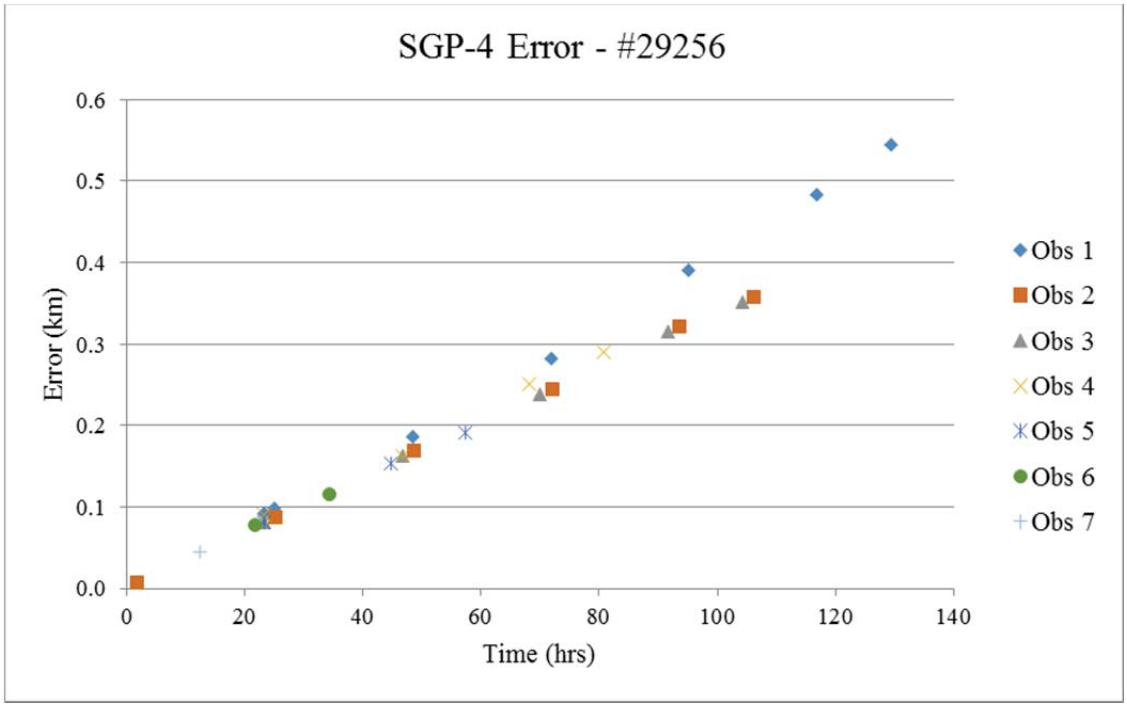

Figure 146. Error of the SGP-4 Propagator Over Time–#29256

VVV. CATALOG NUMBER 31118–SAUDISAT 3

This ephemeris data represents one of three samples for inclinations 90–100 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 220. Two-Line Element for #31118 30NOV–7DEC15

Obs	TLE
1	1 31118U 07012B 15339.17540720 .00000115 00000-0 27370-4 0 9991 2 31118 97.7237 352.2567 0013792 263.6084 96.3555 14.68947294462797
2	1 31118U 07012B 15339.51599318 .00000124 00000-0 29041-4 0 9993 2 31118 97.7237 352.5786 0013780 262.4619 97.5024 14.68947506462847
3	1 31118U 07012B 15339.85657954 .00000101 00000-0 25013-4 0 9991 2 31118 97.7238 352.9006 0013761 261.2172 98.7467 14.68947333462894
4	1 31118U 07012B 15340.19716572 .00000106 00000-0 25809-4 0 9990 2 31118 97.7238 353.2226 0013768 260.0353 99.9300 14.68947496462942
5	1 31118U 07012B 15340.46963454 .00000117 00000-0 27783-4 0 9998 2 31118 97.7239 353.4801 0013768 258.9734 100.9933 14.68947709462989
6	1 31118U 07012B 15340.87833793 .00000104 00000-0 25586-4 0 9990 2 31118 97.7239 353.8663 0013754 257.6462 102.3201 14.68947672463049
7	1 31118U 07012B 15341.21892389 .00000116 00000-0 27637-4 0 9997 2 31118 97.7238 354.1882 0013766 256.5476 103.4199 14.68947917463096
8	1 31118U 07012B 15341.55950982 .00000125 00000-0 29092-4 0 9995 2 31118 97.7239 354.5103 0013758 255.3436 104.6251 14.68948131463148
9	1 31118U 07012B 15341.90009583 .00000117 00000-0 27713-4 0 9995 2 31118 97.7238 354.8321 0013788 254.0374 105.9315 14.68948150463193

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 221. Ephemeris Data Derived From TLEs for #31118

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	5-Dec	4 : 12 : 35.182	14.6895	0.0013792	97.7237	263.6084	352.2567	96.3555
2	5-Dec	12 : 23 : 1.811	14.6895	13780	97.7237	262.4619	352.5786	97.5024
3	5-Dec	20 : 33 : 28.472	14.6895	13761	97.7238	261.2172	352.9006	98.7467
4	6-Dec	4 : 43 : 55.118	14.6895	13768	97.7238	260.0353	353.2226	99.9300
5	6-Dec	11 : 16 : 16.424	14.6895	13768	97.7239	258.9734	353.4801	100.9933
6	6-Dec	21 : 4 : 48.397	14.6895	13754	97.7239	257.6462	353.8663	102.3201
7	7-Dec	5 : 15 : 15.024	14.6895	13766	97.7238	256.5476	354.1882	103.4199
8	7-Dec	13 : 25 : 41.648	14.6895	13758	97.7239	255.3436	354.5103	104.6251
9	7-Dec	21 : 36 : 8.280	14.6895	13788	97.7238	254.0374	354.8321	105.9315

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 222. Error of Propagated Ephemeris for #31118

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.094	145	8.17406
→3	0.194	291	16.34814
→4	0.126	435	24.52220
→5	0.089	552	31.06146
→6	0.194	726	40.87034
→7	0.087	871	49.04440
→8	0.145	1015	57.21846
→9	0.154	1160	65.39253
Obs 2→3	0.301	145	8.17407
→4	0.244	291	16.34814
→5	0.131	407	22.88739
→6	0.346	581	32.69627
→7	0.222	726	40.87034
→8	0.146	871	49.04440
→9	0.210	1015	57.21846
Obs 3→4	0.106	145	8.17407
→5	0.280	261	14.71332
→6	0.116	435	24.52220
→7	0.293	580	32.69626
→8	0.451	725	40.87033
→9	0.491	870	49.04439
Obs 4→5	0.169	116	6.53925
→6	0.040	290	16.34813
→7	0.161	435	24.52220
→8	0.306	580	32.69626
→9	0.309	725	40.87032
Obs 5→6	0.210	174	9.80888
→7	0.054	319	17.98294
→8	0.072	464	26.15701
→9	0.074	609	34.33107
Obs 6→7	0.183	145	8.17406
→8	0.333	290	16.34813
→9	0.338	435	24.52219
Obs 7→8	0.130	145	8.17406
→9	0.121	290	16.34813
Obs 8→9	0.056	145	8.17406

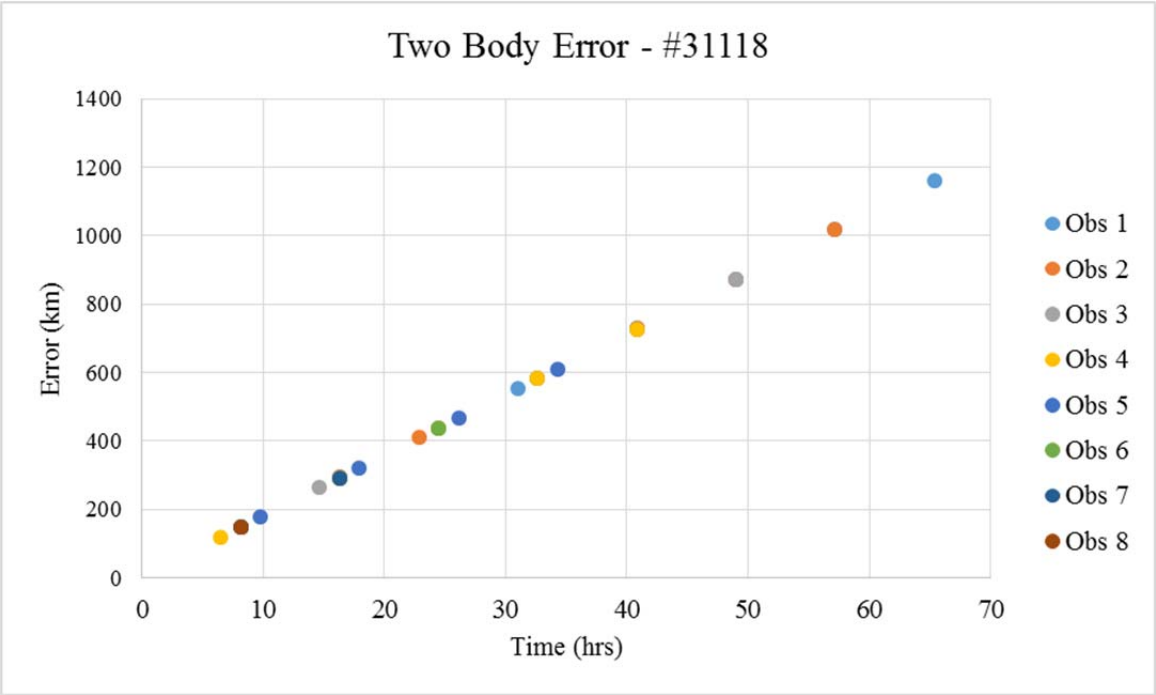

Figure 147. Error of the Two-Body Propagator Over Time–#31118

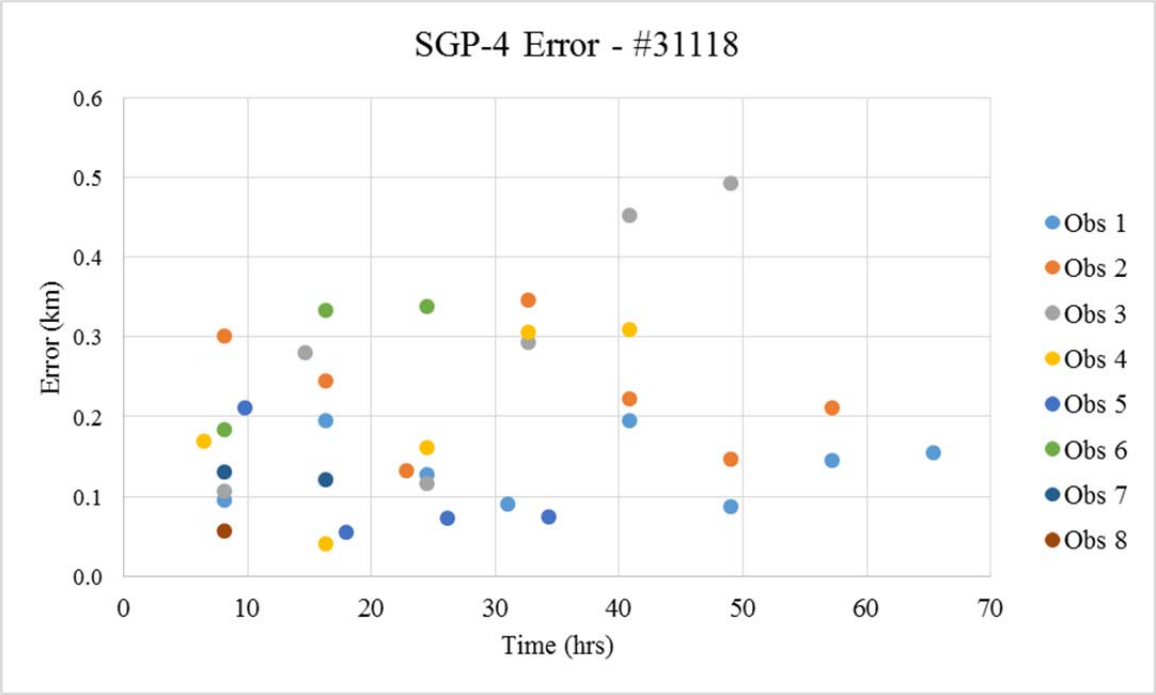

Figure 148. Error of the SGP-4 Propagator Over Time–#31118

WWW. CATALOG NUMBER 33393–DEMOSAT / FALCON 1

This ephemeris data represents one of three samples for inclinations 0–10 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 223. Two-Line Element for #33393 30NOV–7DEC15

Obs	TLE
1	1 33393U 08048A 15335.71449830 +.00001550 +00000-0 +10709-3 0 9995
	2 33393 009.3448 139.9883 0012668 080.0460 280.1168 14.83950110388864
2	1 33393U 08048A 15336.72266930 .00001463 00000-0 96935-4 0 9994
	2 33393 9.3450 132.7745 0012674 94.7316 265.4331 14.83951399389021
3	1 33393U 08048A 15337.66362635 +.00001441 +00000-0 +94273-4 0 9996
	2 33393 009.3450 126.0419 0012732 108.4411 251.7173 14.83952917389152
4	1 33393U 08048A 15338.60458070 .00001414 00000-0 91152-4 0 9993
	2 33393 9.3452 119.3088 0012790 122.1860 237.9580 14.83954403389303
5	1 33393U 08048A 15339.61274371 .00001527 00000-0 10438-3 0 9997
	2 33393 9.3454 112.0950 0012854 136.6965 223.4245 14.83956705389451
6	1 33393U 08048A 15340.62090397 .00001633 00000-0 11672-3 0 9993
	2 33393 9.3456 104.8817 0012962 151.2134 208.8781 14.83959064389605
7	1 33393U 08048A 15341.62906259 .00001624 00000-0 11563-3 0 9996
	2 33393 9.3457 97.6688 0013089 165.5770 194.4803 14.83960686389759

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 224. Ephemeris Data Derived From TLEs for #33393

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	17 : 8 : 52.653	14.8395	0.0012668	9.3448	80.0460	139.9883	280.1168
2	2-Dec	17 : 20 : 38.628	14.8395	12674	9.3450	94.7316	132.7745	265.4331
3	3-Dec	15 : 55 : 37.317	14.8395	12732	9.3450	108.4411	126.0419	251.7173
4	4-Dec	14 : 30 : 35.772	14.8395	12790	9.3452	122.1860	119.3088	237.9580
5	5-Dec	14 : 42 : 21.057	14.8396	12854	9.3454	136.6965	112.0950	223.4245
6	6-Dec	14 : 54 : 6.103	14.8396	12962	9.3456	151.2134	104.8817	208.8781
7	7-Dec	15 : 5 : 51.008	14.8396	13089	9.3457	165.5770	97.6688	194.4803

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 225. Error of Propagated Ephemeris for #33393

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.376	867	24.19610
→3	0.734	1673	46.77907
→4	1.051	2473	69.36198
→5	1.437	3318	93.55789
→6	1.684	4148	117.75374
→7	2.008	4953	141.94954
Obs 2→3	0.293	810	22.58297
→4	0.627	1618	45.16587
→5	0.973	2476	69.36179
→6	1.489	3322	93.55763
→7	1.949	4149	117.75344
Obs 3→4	0.343	811	22.58290
→5	0.694	1677	46.77882
→6	1.263	2536	70.97466
→7	1.771	3379	95.17047
Obs 4→5	0.345	870	24.19591
→6	0.933	1737	48.39176
→7	1.476	2594	72.58757
Obs 5→6	0.314	867	24.19585
→7	0.614	1729	48.39165
Obs 6→7	0.502	872	24.19581

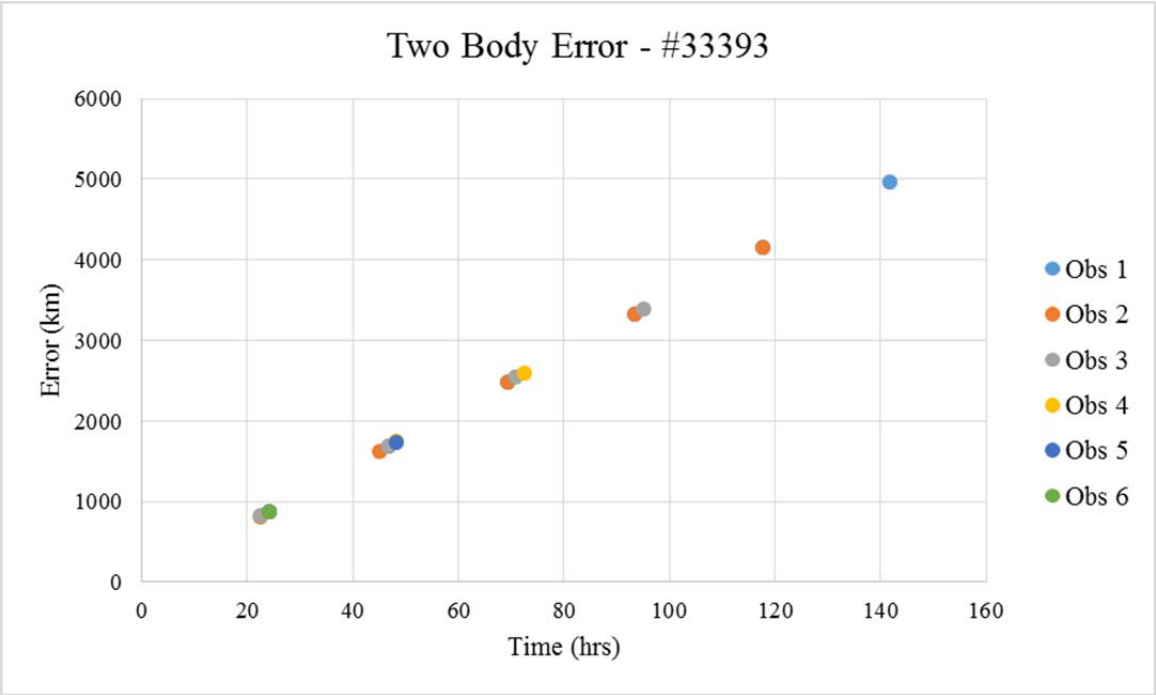

Figure 149. Error of the Two-Body Propagator Over Time–#33393

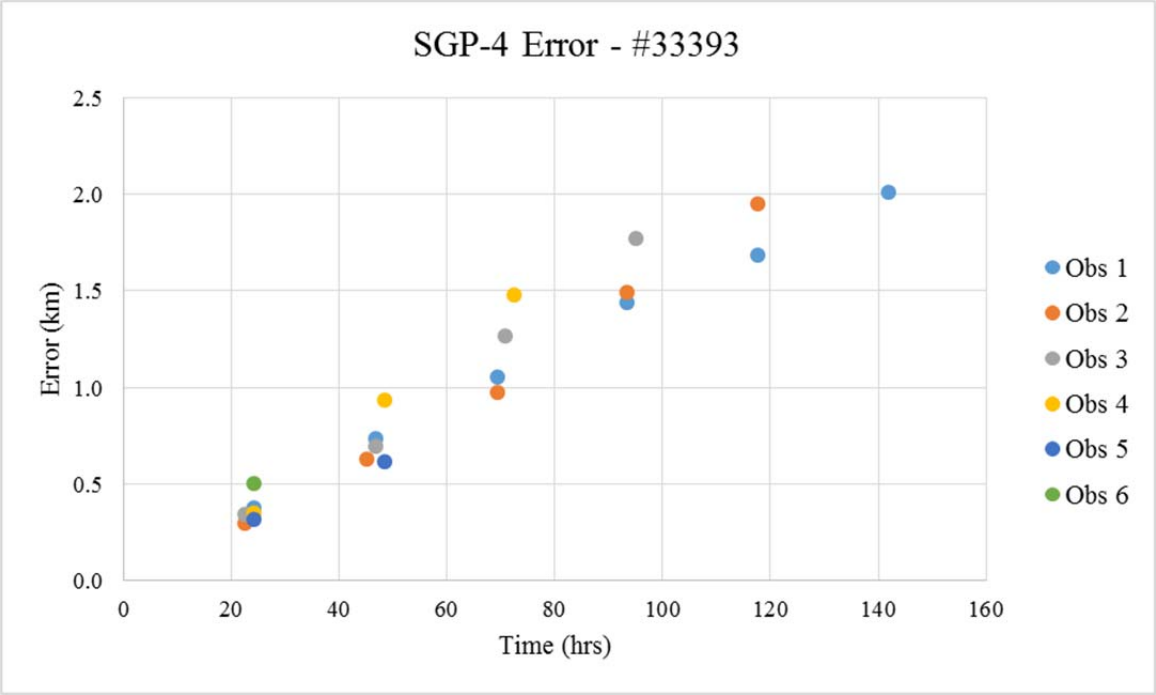

Figure 150. Error of the SGP-4 Propagator Over Time–#33393

XXX. CATALOG NUMBER 34028–COSMOS 2251 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.05-0.06 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 226. Two-Line Element for #34028 30NOV–7DEC15

Obs	TLE
1	1 34028U 93036HP 15334.60385571 +.00000346 +00000-0 +42288-3 0 9999 2 34028 073.8822 191.1170 0554973 220.5101 167.1026 13.18233616326832
2	1 34028U 93036HP 15335.59029735 .00000292 00000-0 36050-3 0 9995 2 34028 73.8820 189.6106 0554957 218.8403 168.4019 13.18233920327169
3	1 34028U 93036HP 15336.97532624 +.00000124 +00000-0 +16743-3 0 9995 2 34028 073.8817 187.4954 0554939 216.4967 261.2590 13.18234306327144
4	1 34028U 93036HP 15337.05349197 .00000106 00000-0 14731-3 0 9991 2 34028 73.8816 187.3761 0554944 216.3655 272.2052 13.18234306327355
5	1 34028U 93036HP 15337.95159933 -.00000029 +00000-0 -81945-5 0 9996 2 34028 073.8815 186.0045 0554918 214.8458 214.3064 13.18234422327270
6	1 34028U 93036HP 15338.93801196 -.00000139 +00000-0 -13472-3 0 9990 2 34028 073.8815 184.4981 0554890 213.1764 215.4734 13.18234539327402
7	1 34028U 93036HP 15339.02572490 -.00000142 00000-0 -13770-3 0 9998 2 34028 73.8815 184.3641 0554882 213.0275 271.7287 13.18234588327616
8	1 34028U 93036HP 15339.93682356 -.00000174 +00000-0 -17451-3 0 9996 2 34028 073.8815 182.9727 0554853 211.4852 275.4804 13.18234674327539
9	1 34028U 93036HP 15340.98835803 -.00000098 00000-0 -88455-4 0 9998 2 34028 73.8815 181.3669 0554809 209.7050 225.6893 13.18235014327879

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 227. Ephemeris Data Derived From TLEs for #34028

Obs	Day	Time			MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	14 :	29 :	33.133	13.1823	0.0554973	73.8822	220.5101	191.1170	167.1026
2	1-Dec	14 :	10 :	1.691	13.1823	554957	73.8820	218.8403	189.6106	168.4019
3	2-Dec	23 :	24 :	28.187	13.1823	554939	73.8817	216.4967	187.4954	261.2590
4	3-Dec	1 :	17 :	1.706	13.1823	554944	73.8816	216.3655	187.3761	272.2052
5	3-Dec	22 :	50 :	18.182	13.1823	554918	73.8815	214.8458	186.0045	214.3064
6	4-Dec	22 :	30 :	44.233	13.1823	554890	73.8815	213.1764	184.4981	215.4734
7	5-Dec	0 :	37 :	2.631	13.1823	554882	73.8815	213.0275	184.3641	271.7287
8	5-Dec	22 :	29 :	1.556	13.1823	554853	73.8815	211.4852	182.9727	275.4804
9	6-Dec	23 :	43 :	14.134	13.1824	554809	73.8815	209.7050	181.3669	225.6893

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 228. Error of Propagated Ephemeris for #34028

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.090	338	23.67460
→3	0.500	688	56.91529
→4	0.556	730	58.79127
→5	0.566	1005	80.34585
→6	0.295	1304	104.01975
→7	0.384	1306	106.12486
→8	0.612	1584	127.99123
→9	2.067	1861	153.22806
Obs 2→3	0.703	401	33.24069
→4	0.776	435	35.11667
→5	1.057	711	56.67125
→6	1.107	1010	80.34515
→7	1.200	1012	82.45026
→8	0.729	1288	104.31663
→9	0.417	1578	129.55346
Obs 3→4	0.084	23	1.87598
→5	0.671	295	23.43055
→6	1.155	595	47.10446
→7	1.288	602	49.20957
→8	1.377	875	71.07594
→9	1.034	1178	96.31276
Obs 4→5	0.590	271	21.55458
→6	1.105	571	45.22848
→7	1.256	579	47.33359
→8	1.392	852	69.19996
→9	1.102	1155	94.43679
Obs 5→6	0.626	300	23.67390
→7	0.756	315	25.77901
→8	1.119	585	47.64538
→9	1.230	894	72.88221
Obs 6→7	0.077	26	2.10511
→8	0.434	294	23.97148
→9	0.685	605	49.20831
Obs 7→8	0.327	268	21.86637
→9	0.561	580	47.10320
Obs 8→9	0.137	311	25.23683

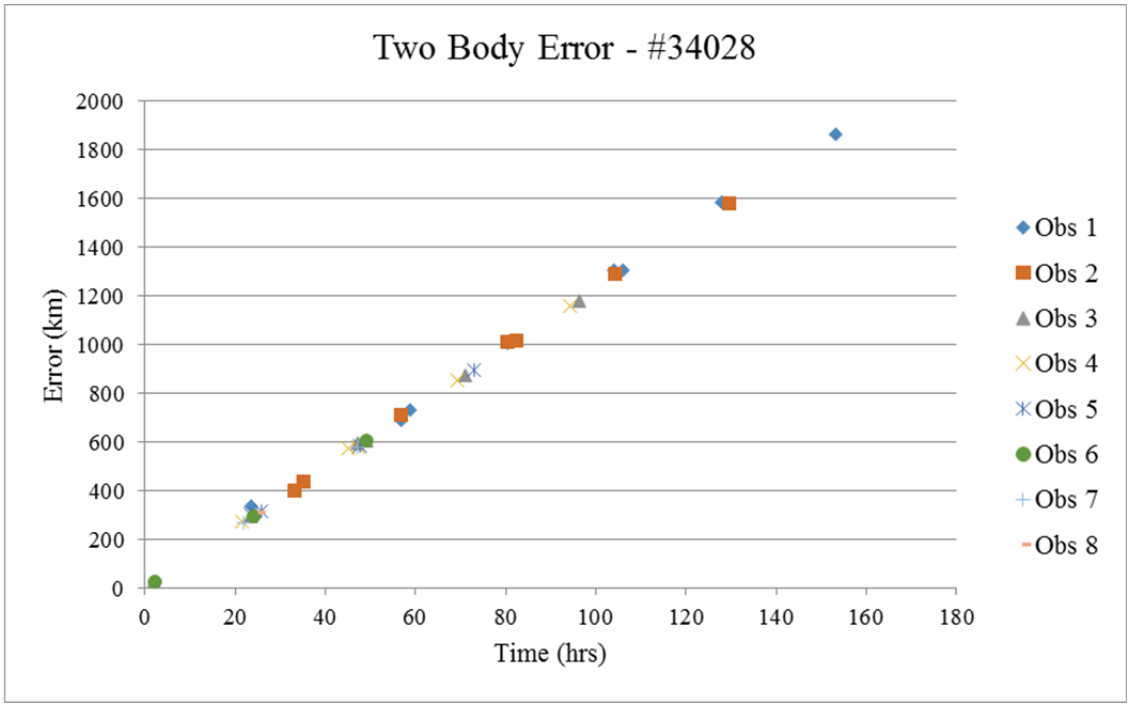

Figure 151. Error of the Two-Body Propagator Over Time–#34028

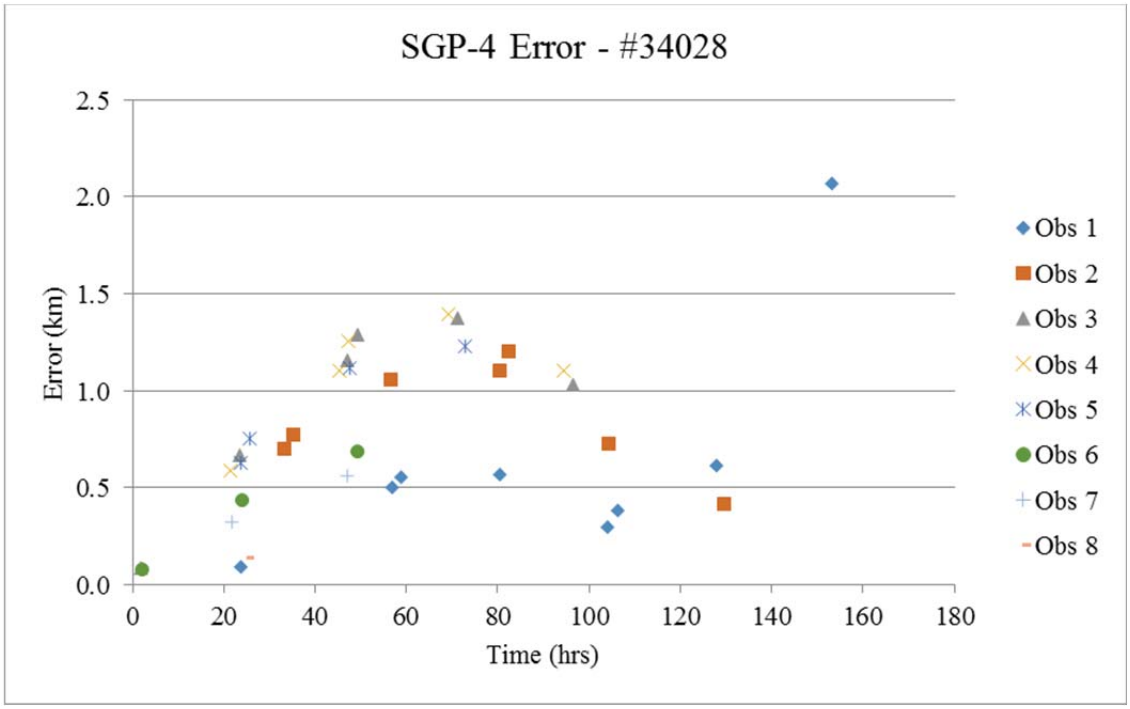

Figure 152. Error of the SGP-4 Propagator Over Time–#34028

YYY. CATALOG NUMBER 35646–COSMOS 2251 DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.04-0.05 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 229. Two-Line Element for #35646 30NOV–7DEC15

Obs	TLE
1	1 35646U 93036ANM 15334.99843928 .00000265 00000-0 29157-3 0 9993 2 35646 73.8739 78.7965 0471503 90.3176 25.7854 13.36113559328620
2	1 35646U 93036ANM 15335.75403697 +.00000256 +00000-0 +28190-3 0 9999 2 35646 073.8739 077.6074 0471457 088.9945 060.2236 13.36113981328700
3	1 35646U 93036ANM 15336.72673848 +.00000216 +00000-0 +24114-3 0 9992 2 35646 073.8741 076.0766 0471392 087.2908 058.9373 13.36114393328831
4	1 35646U 93036ANM 15337.02093959 .00000214 00000-0 23886-3 0 9998 2 35646 73.8741 75.6135 0471385 86.7751 34.0512 13.36114564328894
5	1 35646U 93036ANM 15337.99240834 +.00000192 +00000-0 +21651-3 0 9993 2 35646 073.8742 074.0847 0471334 085.0736 026.8374 13.36114986329004
6	1 35646U 93036ANM 15339.24895988 .00000210 00000-0 23522-3 0 9999 2 35646 73.8742 72.1071 0471257 82.8727 310.8804 13.36115721329193
7	1 35646U 93036ANM 15340.69481903 +.00000258 +00000-0 +28468-3 0 9994 2 35646 073.8743 069.8318 0471188 080.3384 065.5042 13.36116826329360
8	1 35646U 93036ANM 15341.57598470 .00000270 00000-0 29692-3 0 9994 2 35646 73.8744 68.4450 0471146 78.7940 343.9373 13.36117296329504

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 230. Ephemeris Data Derived From TLEs for #35646

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	23 : 57 : 45.154	13.3611	0.0471503	73.8739	90.3176	78.7965	25.7854
2	1-Dec	18 : 5 : 48.794	13.3611	471457	73.8739	88.9945	77.6074	60.2236
3	2-Dec	17 : 26 : 30.205	13.3611	471392	73.8741	87.2908	76.0766	58.9373
4	3-Dec	0 : 30 : 9.181	13.3611	471385	73.8741	86.7751	75.6135	34.0512
5	3-Dec	23 : 49 : 4.081	13.3611	471334	73.8742	85.0736	74.0847	26.8374
6	5-Dec	5 : 58 : 30.134	13.3612	471257	73.8742	82.8727	72.1071	310.8804
7	6-Dec	16 : 40 : 32.364	13.3612	471188	73.8743	80.3384	69.8318	65.5042
8	7-Dec	13 : 49 : 25.078	13.3612	471146	73.8744	78.7940	68.4450	343.9373

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 231. Error of Propagated Ephemeris for #35646

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	0.061	246	18.13434
→3	0.147	508	41.47918
→4	0.244	594	48.54001
→5	0.37	851	71.85526
→6	0.674	1359	102.01249
→7	0.435	1861	136.71311
→8	0.945	1840	157.86109
Obs 2→3	0.09	285	23.34484
→4	0.169	371	30.40566
→5	0.302	635	53.72091
→6	0.593	1120	83.87815
→7	0.386	1613	118.57877
→8	0.975	1633	139.72675
Obs 3→4	0.057	86	7.06083
→5	0.258	358	30.37608
→6	0.638	810	60.53331
→7	0.659	1293	95.23393
→8	1.508	1365	116.38191
Obs 4→5	0.185	275	23.31525
→6	0.546	716	53.47249
→7	0.577	1197	88.17311
→8	1.388	1284	109.32108
Obs 5→6	0.338	405	30.15724
→7	0.572	879	64.85786
→8	1.334	1013	86.00583
Obs 6→7	0.282	469	34.70062
→8	0.718	660	55.84860
Obs 7→8	0.039	255	21.14798

Figure 153. Error of the Two-Body Propagator Over Time–#35646

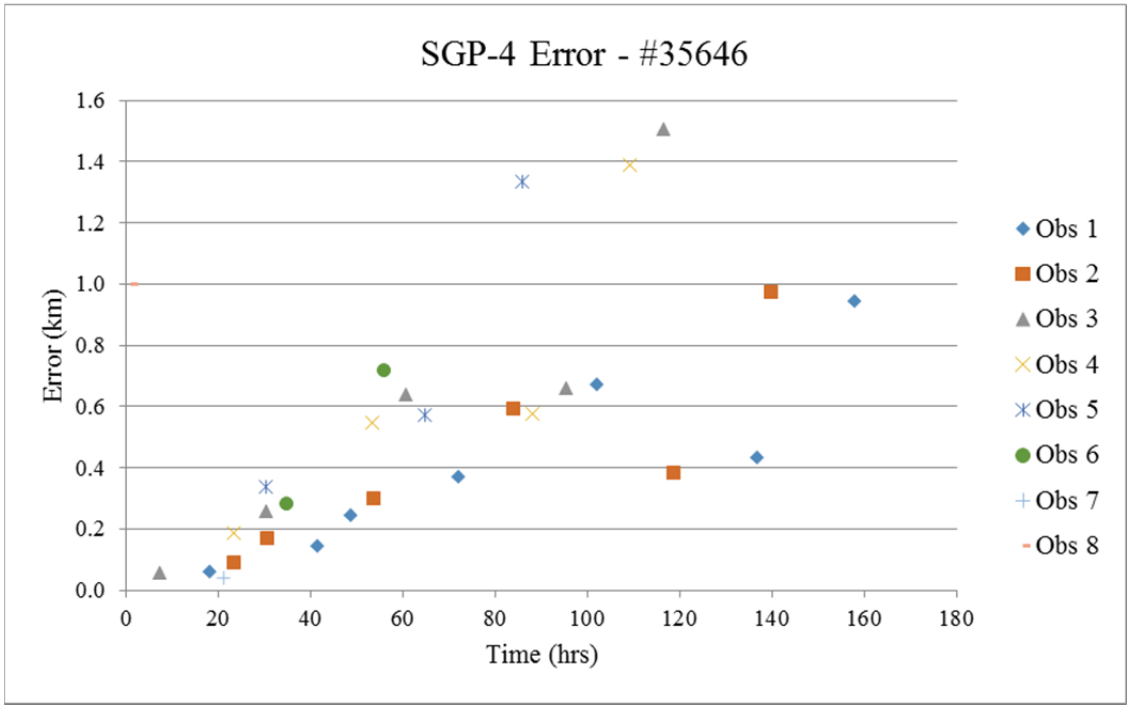

Figure 154. Error of the SGP-4 Propagator Over Time–#35646

ZZZ. CATALOG NUMBER 37379–JASON DEBRIS

This ephemeris data represents one of three samples for eccentricities 0.01-0.02 used in the experiment to determine the effect of eccentricity on propagator accuracy.

Table 232. Two-Line Element for #37379 30NOV–7DEC15

Obs	TLE
1	1 37379U 01055G 15335.02398234 .00002358 00000-0 52002-2 0 9997 2 37379 66.1172 343.3456 0153610 259.9295 129.2801 13.25653474656830
2	1 37379U 01055G 15336.98428492 .00001479 00000-0 33186-2 0 9998 2 37379 66.1180 338.9484 0153252 260.1077 123.3870 13.25659163657095
3	1 37379U 01055G 15337.38124394 -.00001583 00000-0 -32477-2 0 9997 2 37379 66.1164 338.0559 0153089 260.0189 217.6987 13.25649822657156
4	1 37379U 01055G 15338.94560920 +.00001780 +00000-0 +39654-2 0 9990 2 37379 066.1158 334.5463 0152436 260.1591 122.4984 13.25661567657337
5	1 37379U 01055G 15339.10484328 .00000947 00000-0 21791-2 0 9993 2 37379 66.1156 334.1892 0152371 260.1849 162.3178 13.25660817657370
6	1 37379U 01055G 15339.42544688 -.00000354 +00000-0 -61030-3 0 9999 2 37379 066.1142 333.4694 0152324 260.2309 252.1445 13.25657283657397
7	1 37379U 01055G 15340.00336362 .00000026 00000-0 20457-3 0 9995 2 37379 66.1148 332.1733 0151943 260.2419 129.8679 13.25655687657497
8	1 37379U 01055G 15340.40579613 +.00000778 +00000-0 +18193-2 0 9994 2 37379 066.1136 331.2700 0151773 260.3344 250.1207 13.25655419657529
9	1 37379U 01055G 15341.14472581 .00001736 00000-0 38749-2 0 9996 2 37379 66.1144 329.6130 0151180 260.3917 176.1305 13.25657803657642

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 233. Ephemeris Data Derived From TLEs for #37379

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	0 : 34 : 32.074	13.2565	0.0153610	66.1172	259.9295	343.3456	129.2801
2	2-Dec	23 : 37 : 22.217	13.2566	153252	66.1180	260.1077	338.9484	123.3870
3	3-Dec	9 : 8 : 59.476	13.2565	153089	66.1164	260.0189	338.0559	217.6987
4	4-Dec	22 : 41 : 40.635	13.2566	152436	66.1158	260.1591	334.5463	122.4984
5	5-Dec	2 : 30 : 58.459	13.2566	152371	66.1156	260.1849	334.1892	162.3178
6	5-Dec	10 : 12 : 38.610	13.2566	152324	66.1142	260.2309	333.4694	252.1445
7	6-Dec	0 : 4 : 50.617	13.2566	151943	66.1148	260.2419	332.1733	129.8679
8	6-Dec	9 : 44 : 20.786	13.2566	151773	66.1136	260.3344	331.2700	250.1207
9	7-Dec	3 : 28 : 24.310	13.2566	151180	66.1144	260.3917	329.6130	176.1305

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 234. Error of Propagated Ephemeris for #37379

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hrs)
Obs 1→2	2.123	605	47.04726
→3	1.231	507	56.57428
→4	10.147	1218	94.11904
→5	5.649	925	97.94066
→6	12.145	1306	105.63515
→7	17.577	1488	119.50515
→8	21.048	1588	129.16353
→9	21.746	1183	146.89784
Obs 2→3	1.479	88	9.52702
→4	4.742	617	47.07178
→5	2.297	491	50.89340
→6	5.015	730	58.58789
→7	8.871	915	72.45789
→8	9.897	1019	82.11627
→9	9.973	827	99.85058
Obs 3→4	9.122	487	37.54477
→5	12.573	392	41.36638
→6	13.549	604	49.06087
→7	16.656	787	62.93087
→8	20.755	890	72.58925
→9	30.489	732	90.32356
Obs 4→5	0.328	37	3.82162
→6	0.981	143	11.51610
→7	3.172	322	25.38611
→8	4.598	434	35.04449
→9	5.654	440	52.77880
Obs 5→6	0.827	96	7.69449
→7	2.409	274	21.56449
→8	3.319	387	31.22287
→9	3.201	409	48.95718
Obs 6→7	0.706	176	13.87000
→8	0.995	291	23.52838
→9	2.55	345	41.26269
Obs 7→8	0.519	120	9.65838
→9	2.290	229	27.39269
Obs 8→9	1.691	148	17.73431

Figure 155. Error of the Two-Body Propagator Over Time–#37379

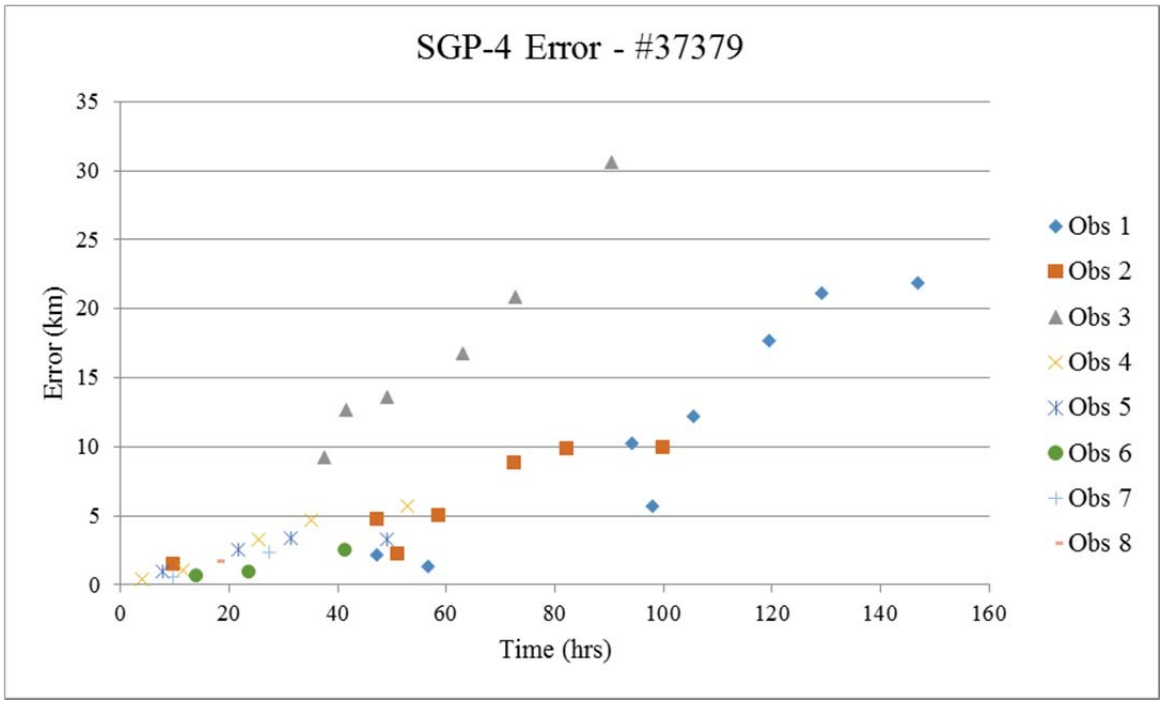

Figure 156. Error of the SGP-4 Propagator Over Time–#37379

AAAA. CATALOG NUMBER 37789–NIGERIASAT 2

This ephemeris data represents one of three samples for inclinations 90–100 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 235. Two-Line Element for #37789 30NOV–7DEC15

Obs	TLE
1	1 37789U 11044B 15335.19848844 .00000113 00000-0 31803-4 0 9991 2 37789 98.1053 48.4439 0011389 11.1670 348.9781 14.61930445228618
2	1 37789U 11044B 15335.47226194 .00000113 00000-0 31908-4 0 9996 2 37789 98.1054 48.7124 0011334 10.4094 349.7341 14.61930547228653
3	1 37789U 11044B 15335.81447882 .00000104 00000-0 30135-4 0 9994 2 37789 98.1053 49.0479 0011314 9.3464 350.7937 14.61930552228700
4	1 37789U 11044B 15336.15669592 .00000107 00000-0 30622-4 0 9990 2 37789 98.1053 49.3835 0011308 8.2229 351.9157 14.61930670228752
5	1 37789U 11044B 15336.49891283 .00000104 00000-0 30072-4 0 9997 2 37789 98.1053 49.7191 0011288 7.1911 352.9452 14.61930754228802
6	1 37789U 11044B 15336.84112962 .00000099 00000-0 29064-4 0 9998 2 37789 98.1053 50.0546 0011286 6.1273 354.0054 14.61930793228858
7	1 37789U 11044B 15337.18334665 .00000112 00000-0 31655-4 0 9997 2 37789 98.1051 50.3901 0011270 4.9753 355.1571 14.61931049228903
8	1 37789U 11044B 15337.32023313 .00000111 00000-0 31497-4 0 9991 2 37789 98.1051 50.5244 0011260 4.5658 355.5645 14.61931088228925
9	1 37789U 11044B 15337.79933645 .00000108 00000-0 30898-4 0 9990 2 37789 98.1050 50.9941 0011212 3.1562 356.9701 14.61931220228991
10	1 37789U 11044B 15338.20999673 .00000113 00000-0 31889-4 0 9997 2 37789 98.1051 51.3967 0011203 1.8917 358.2328 14.61931389229058
11	1 37789U 11044B 15338.48377011 .00000109 00000-0 31093-4 0 9995 2 37789 98.1050 51.6653 0011177 1.0735 359.0489 14.61931435229095
12	1 37789U 11044B 15338.82598679 .00000098 00000-0 28912-4 0 9991 2 37789 98.1049 52.0006 0011155 359.9668 0.1520 14.61931417229142
13	1 37789U 11044B 15339.16820374 .00000108 00000-0 30887-4 0 9995 2 37789 98.1049 52.3360 0011137 358.8313 1.2872 14.61931632229199

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 236. Ephemeris Data Derived From TLEs for #37789

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	4 : 45 : 49.401	14.6193	0.0011389	98.1053	11.1670	48.4439	348.9781
2	1-Dec	11 : 20 : 3.432	14.6193	11334	98.1054	10.4094	48.7124	349.7341
3	1-Dec	19 : 32 : 50.970	14.6193	11314	98.1053	9.3464	49.0479	350.7937
4	2-Dec	3 : 45 : 38.527	14.6193	11308	98.1053	8.2229	49.3835	351.9157
5	2-Dec	11 : 58 : 26.069	14.6193	11288	98.1053	7.1911	49.7191	352.9452
6	2-Dec	20 : 11 : 13.599	14.6193	11286	98.1053	6.1273	50.0546	354.0054
7	3-Dec	4 : 24 : 1.151	14.6193	11270	98.1051	4.9753	50.3901	355.1571
8	3-Dec	7 : 41 : 8.142	14.6193	11260	98.1051	4.5658	50.5244	355.5645
9	3-Dec	19 : 11 : 2.669	14.6193	11212	98.1050	3.1562	50.9941	356.9701
10	4-Dec	5 : 2 : 23.717	14.6193	11203	98.1051	1.8917	51.3967	358.2328
11	4-Dec	11 : 36 : 37.738	14.6193	11177	98.1050	1.0735	51.6653	359.0489
12	4-Dec	19 : 49 : 25.259	14.6193	11155	98.1049	359.9668	52.0006	0.1520
13	5-Dec	4 : 2 : 12.803	14.6193	11137	98.1049	358.8313	52.3360	1.2872

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 237. Error of Propagated Ephemeris for #37789

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.084	115	6.57056
→3	0.055	259	14.78377
→4	0.059	403	22.99698
→5	0.074	546	31.21019
→6	0.13	690	39.42339
→7	0.099	834	47.63660
→8	0.114	891	50.92187
→9	0.158	1092	62.42035
→10	0.181	1263	72.27620
→11	0.181	1378	78.84676
→12	0.168	1521	87.05996
→13	0.201	1663	95.27317
Obs 2→3	0.081	144	8.21321
→4	0.076	288	16.42642
→5	0.089	432	24.63962
→6	0.189	575	32.85282
→7	0.053	719	41.06603
→8	0.053	776	44.35131
→9	0.088	977	55.84979
→10	0.102	1149	65.70563
→11	0.112	1263	72.27620
→12	0.169	1406	80.48940
→13	0.148	1549	88.70260
Obs 3→4	0.024	144	8.21321
→5	0.039	288	16.42642
→6	0.055	431	24.63962
→7	0.131	575	32.85283
→8	0.155	632	36.13810
→9	0.219	833	47.63658
→10	0.268	1005	57.49243
→11	0.267	1120	64.06299
→12	0.194	1263	72.27619
→13	0.313	1406	80.48940
Obs 4→5	0.018	144	8.21321
→6	0.08	288	16.42641
→7	0.101	431	24.63962
→8	0.124	489	27.92489
→9	0.184	690	39.42337
→10	0.229	862	49.27922

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→11	0.226	977	55.84978
→12	0.156	1120	64.06298
→13	0.266	1263	72.27619
Obs 5→6	0.082	144	8.21320
→7	0.1	288	16.42641
→8	0.124	345	19.71169
→9	0.189	546	31.21017
→10	0.24	718	41.06601
→11	0.238	833	47.63657
→12	0.167	977	55.84978
→13	0.29	1120	64.06298
Obs 6→7	0.191	144	8.21321
→8	0.219	201	11.49848
→9	0.296	402	22.99696
→10	0.362	575	32.85281
→11	0.367	690	39.42337
→12	0.297	833	47.63657
→13	0.44	976	55.84978
Obs 7→8	0.022	57	3.28528
→9	0.071	259	14.78376
→10	0.103	431	24.63960
→11	0.099	546	31.21016
→12	0.09	690	39.42336
→13	0.127	833	47.63657
Obs 8→9	0.054	201	11.49848
→10	0.087	374	21.35433
→11	0.082	489	27.92489
→12	0.092	632	36.13809
→13	0.118	776	44.35129
Obs 9→10	0.039	172	9.85585
→11	0.037	287	16.42641
→12	0.087	431	24.63961
→13	0.077	575	32.85281
Obs 10→11	0.035	115	6.57056
→12	0.132	259	14.78376
→13	0.056	402	22.99697
Obs 11→12	0.103	144	8.21320
→13	0.06	287	16.42641
Obs 12→13	0.145	144	8.21321

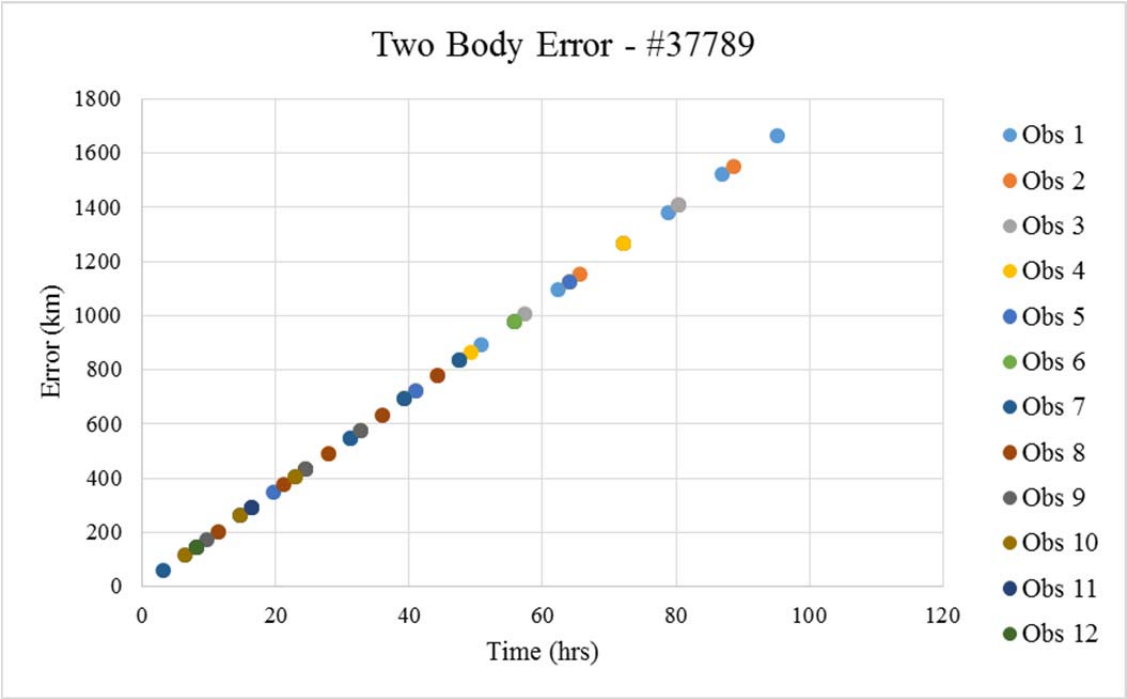

Figure 157. Error of the Two-Body Propagator Over Time–#37789

Figure 158. Error of the SGP-4 Propagator Over Time–#37789

BBBB. CATALOG NUMBER 37839–JUGNU

This ephemeris data represents one of three samples for inclinations 10–20 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 238. Two-Line Element for #37839 30NOV–7DEC15

Obs	TLE
1	1 37839U 11058B 15334.93385414 +.00000383 +00000-0 +62583-4 0 9990 2 37839 019.9615 271.6202 0019125 084.4878 328.9766 14.12507266213719
2	1 37839U 11058B 15335.84788244 .00000380 00000-0 60751-4 0 9991 2 37839 19.9614 266.0791 0019136 94.4921 296.9005 14.12507449213950
3	1 37839U 11058B 15335.92496641 +.00000375 +00000-0 +58336-4 0 9997 2 37839 019.9614 265.6117 0019142 095.3353 328.8803 14.12507424213856
4	1 37839U 11058B 15336.91297076 .00000368 00000-0 54623-4 0 9995 2 37839 19.9613 259.6219 0019148 106.1117 313.0183 14.12507607214105
5	1 37839U 11058B 15337.90253975 +.00000354 +00000-0 +47103-4 0 9995 2 37839 019.9611 253.6225 0019138 116.9324 305.0853 14.12507692214134
6	1 37839U 11058B 15337.97800039 .00000354 00000-0 47090-4 0 9996 2 37839 19.9611 253.1650 0019143 117.7583 328.8105 14.12507716214256
7	1 37839U 11058B 15338.96757546 +.00000351 +00000-0 +45424-4 0 9996 2 37839 019.9610 247.1653 0019146 128.5929 320.8958 14.12507866214285
8	1 37839U 11058B 15339.11858837 .00000350 00000-0 44875-4 0 9997 2 37839 19.9609 246.2498 0019148 130.2403 8.8174 14.12507902214418
9	1 37839U 11058B 15339.88205655 +.00000361 +00000-0 +50471-4 0 9996 2 37839 019.9608 241.6211 0019147 138.5936 291.1335 14.12508082214416
10	1 37839U 11058B 15340.94669848 +.00000366 +00000-0 +53087-4 0 9994 2 37839 019.9606 235.1663 0019131 150.2800 304.9132 14.12508310214565
11	1 37839U 11058B 15341.02531713 .00000368 00000-0 54255-4 0 9993 2 37839 19.9606 234.6896 0019136 151.1399 344.6979 14.12508353214685

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 239. Ephemeris Data Derived From TLEs for #37839

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22 : 24 : 44.998	14.1251	0.0019125	19.9615	84.4878	271.6202	328.9766
2	1-Dec	20 : 20 : 57.043	14.1251	19136	19.9614	94.4921	266.0791	296.9005
3	1-Dec	22 : 11 : 57.098	14.1251	19142	19.9614	95.3353	265.6117	328.8803
4	2-Dec	21 : 54 : 40.674	14.1251	19148	19.9613	106.1117	259.6219	313.0183
5	3-Dec	21 : 39 : 39.434	14.1251	19138	19.9611	116.9324	253.6225	305.0853
6	3-Dec	23 : 28 : 19.234	14.1251	19143	19.9611	117.7583	253.1650	328.8105
7	4-Dec	23 : 13 : 18.520	14.1251	19146	19.9610	128.5929	247.1653	320.8958
8	5-Dec	2 : 50 : 46.035	14.1251	19148	19.9609	130.2403	246.2498	8.8174
9	5-Dec	21 : 10 : 9.686	14.1251	19147	19.9608	138.5936	241.6211	291.1335
10	6-Dec	22 : 43 : 14.749	14.1251	19131	19.9606	150.2800	235.1663	304.9132
11	7-Dec	0 : 36 : 27.400	14.1251	19136	19.9606	151.1399	234.6896	344.6979

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 240. Error of Propagated Ephemeris for #37839

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.147	650	21.93668
→3	0.097	679	23.78669
→4	0.203	1369	47.49880
→5	0.324	2054	71.24845
→6	0.136	2045	73.05951
→7	0.282	2704	96.80931
→8	0.685	2801	100.43362
→9	0.527	3399	118.75686
→10	0.533	4004	144.30826
→11	1.019	3991	146.19511
Obs 2→3	0.055	52	1.85002
→4	0.116	734	25.56212
→5	0.238	1417	49.31178
→6	0.106	1429	51.12283
→7	0.227	2090	74.87263
→8	0.548	2210	78.49694
→9	0.421	2768	96.82018
→10	0.42	3400	122.37158
→11	0.866	3424	124.25843
Obs 3→4	0.108	680	23.71210
→5	0.179	1363	47.46176
→6	0.027	1378	49.27282
→7	0.103	2039	73.02262
→8	0.513	2159	76.64693
→9	0.294	2715	94.97016
→10	0.253	3349	120.52157
→11	0.808	3376	122.40842

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.106	679	23.74966
→6	0.038	714	25.56071
→7	0.101	1376	49.31051
→8	0.366	1506	52.93482
→9	0.217	2032	71.25806
→10	0.185	2692	96.80947
→11	0.66	2750	98.69631
Obs 5→6	0.029	51	1.81106
→7	0.033	713	25.56086
→8	0.221	837	29.18517
→9	0.135	1350	47.50840
→10	0.215	2034	73.05981
→11	0.555	2109	74.94666
Obs 6→7	0.015	663	23.74980
→8	0.197	786	27.37411
→9	0.116	1298	45.69735
→10	0.181	1983	71.24875
→11	0.527	2059	73.13560
Obs 7→8	0.053	105	3.62431
→9	0.076	621	21.94755
→10	0.196	1323	47.49895
→11	0.397	1403	49.38580
Obs 8→9	0.05	518	18.32324
→10	0.146	1222	43.87464
→11	0.345	1302	45.76149
Obs 9→10	0.083	712	25.55141
→11	0.208	786	27.43825
Obs 10→11	0.024	55	1.88685

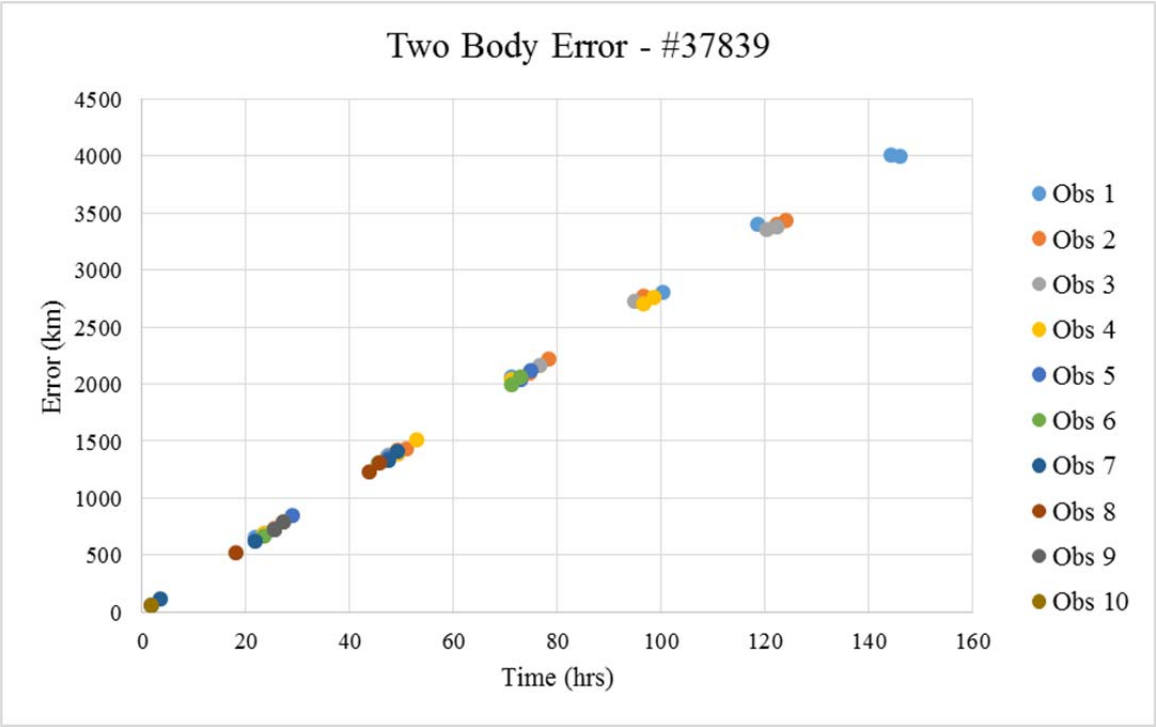

Figure 159. Error of the Two-Body Propagator Over Time–#37839

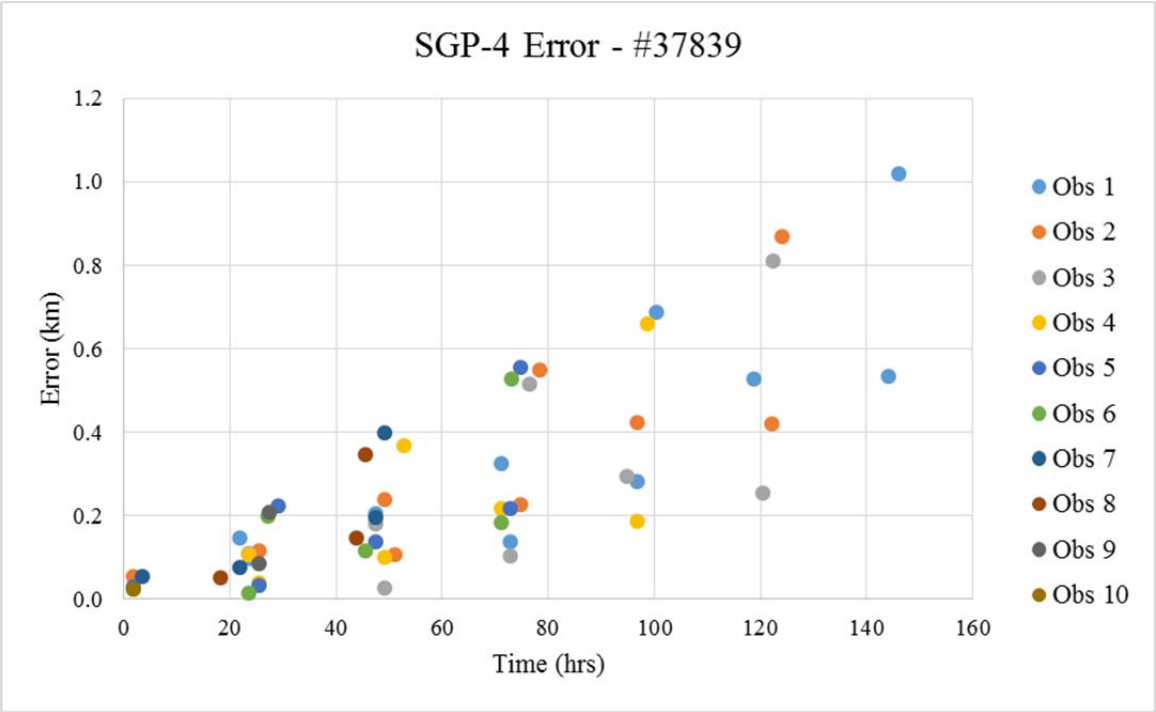

Figure 160. Error of the SGP-4 Propagator Over Time–#37839

CCCC. CATALOG NUMBER 37841–SRMSAT

This ephemeris data represents one of three samples for inclinations 10–20 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 241. Two-Line Element for #37841 30NOV–7DEC15

Obs	TLE
1	1 37841U 11058D 15334.96980831 +.00000355 +00000-0 +50603-4 0 9999 2 37841 019.9728 301.5064 0011827 005.0959 041.3038 14.10512117213432
2	1 37841U 11058D 15335.96088127 +.00000354 +00000-0 +49659-4 0 9995 2 37841 019.9727 295.5183 0011859 015.9728 033.8216 14.10512272213575
3	1 37841U 11058D 15336.03469421 .00000353 00000-0 49332-4 0 9991 2 37841 19.9727 295.0724 0011865 16.7972 48.6182 14.10512288213672
4	1 37841U 11058D 15336.95016002 +.00000347 +00000-0 +45846-4 0 9994 2 37841 019.9726 289.5412 0011890 026.8129 017.2463 14.10512401213713
5	1 37841U 11058D 15337.94122457 +.00000345 +00000-0 +44732-4 0 9997 2 37841 019.9725 283.5532 0011934 037.6662 009.7465 14.10512574213854
6	1 37841U 11058D 15338.01700987 .00000345 00000-0 44580-4 0 9997 2 37841 19.9725 283.0953 0011939 38.5037 34.5671 14.10512597213958
7	1 37841U 11058D 15338.93229544 +.00000343 +00000-0 +43688-4 0 9999 2 37841 019.9724 277.5652 0011965 048.4850 002.3137 14.10512738213994
8	1 37841U 11058D 15339.23472713 .00000342 00000-0 42965-4 0 9997 2 37841 19.9723 275.7379 0011970 51.7606 98.0604 14.10512808214137
9	1 37841U 11058D 15339.92030948 +.00000353 +00000-0 +49187-4 0 9998 2 37841 019.9722 271.5955 0011988 059.2683 339.3619 14.10512978214132
10	1 37841U 11058D 15340.99001619 .00000358 00000-0 51866-4 0 9992 2 37841 19.9720 265.1323 0012004 70.9012 11.2807 14.10513192214374

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 242. Ephemeris Data Derived From TLEs for #37841

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	23 : 16 : 31.438	14.1051	0.0011827	19.9728	5.0959	301.5064	41.3038
2	1-Dec	23 : 3 : 40.142	14.1051	11859	19.9727	15.9728	295.5183	33.8216
3	2-Dec	0 : 49 : 57.580	14.1051	11865	19.9727	16.7972	295.0724	48.6182
4	2-Dec	22 : 48 : 13.826	14.1051	11890	19.9726	26.8129	289.5412	17.2463
5	3-Dec	22 : 35 : 21.803	14.1051	11934	19.9725	37.6662	283.5532	9.7465
6	4-Dec	0 : 24 : 29.653	14.1051	11939	19.9725	38.5037	283.0953	34.5671
7	4-Dec	22 : 22 : 30.326	14.1051	11965	19.9724	48.4850	277.5652	2.3137
8	5-Dec	5 : 38 : 0.424	14.1051	11970	19.9723	51.7606	275.7379	98.0604
9	5-Dec	22 : 5 : 14.739	14.1051	11988	19.9722	59.2683	271.5955	339.3619
10	6-Dec	23 : 45 : 37.399	14.1051	12004	19.9720	70.9012	265.1323	11.2807

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 243. Error of Propagated Ephemeris for #37841

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.123	690	23.78575
→3	0.089	729	25.55726
→4	0.263	1392	47.52844
→5	0.376	2089	71.31399
→6	0.180	2080	73.13284
→7	0.472	2781	95.09969
→8	0.766	2903	102.35805
→9	0.722	3497	118.81203
→10	0.203	4080	144.48499
Obs 2→3	0.014	50	1.77151
→4	0.129	693	23.74269
→5	0.254	1388	47.52824
→6	0.146	1399	49.34709
→7	0.356	2082	71.31394
→8	0.604	2254	78.57230
→9	0.576	2804	95.02628
→10	0.248	3408	120.69924
Obs 3→4	0.120	641	21.97118
→5	0.245	1336	45.75673
→6	0.135	1349	47.57558
→7	0.347	2030	69.54243
→8	0.589	2205	76.80079
→9	0.566	2752	93.25477
→10	0.241	3358	118.92773

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.147	692	23.78555
→6	0.118	723	25.60440
→7	0.262	1385	47.57125
→8	0.465	1589	54.82961
→9	0.460	2104	71.28359
→10	0.357	2736	96.95655
Obs 5→6	0.007	51	1.81885
→7	0.124	689	23.78570
→8	0.255	907	31.04406
→9	0.305	1400	47.49804
→10	0.267	2061	73.17100
Obs 6→7	0.113	636	21.96685
→8	0.237	855	29.22521
→9	0.292	1346	45.67919
→10	0.252	2010	71.35215
Obs 7→8	0.075	214	7.25836
→9	0.163	696	23.71234
→10	0.209	1389	49.38530
Obs 8→9	0.104	482	16.45398
→10	0.134	1184	42.12694
Obs 9→10	0.057	720	25.67296

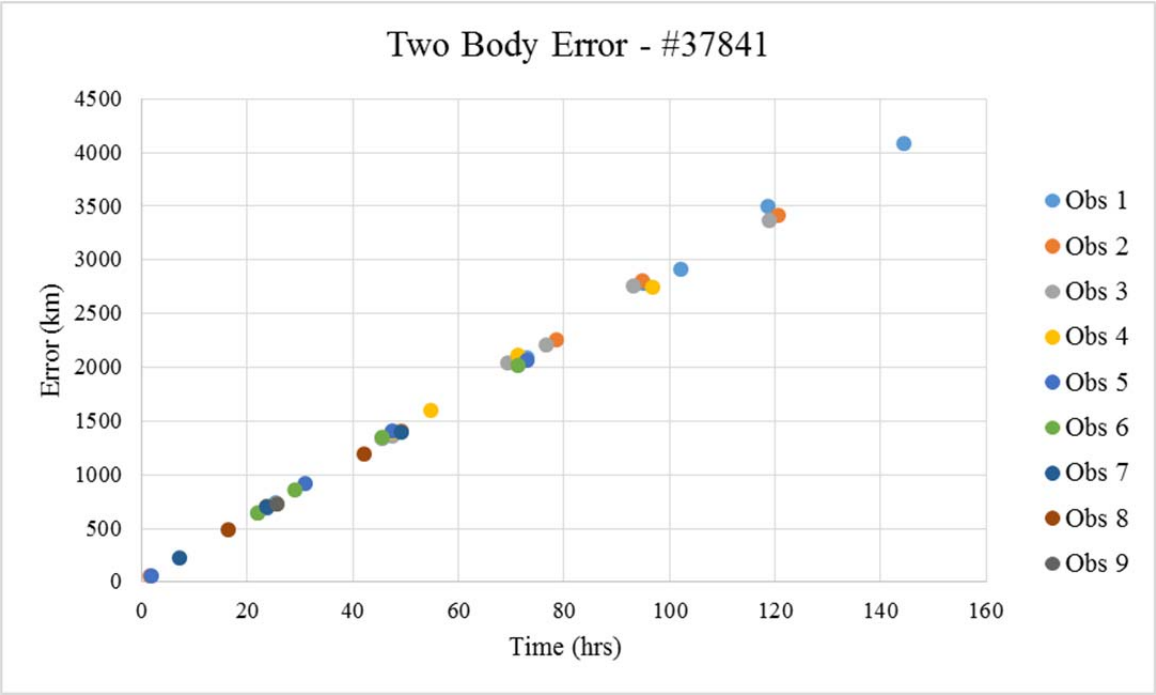

Figure 161. Error of the Two-Body Propagator Over Time–#37841

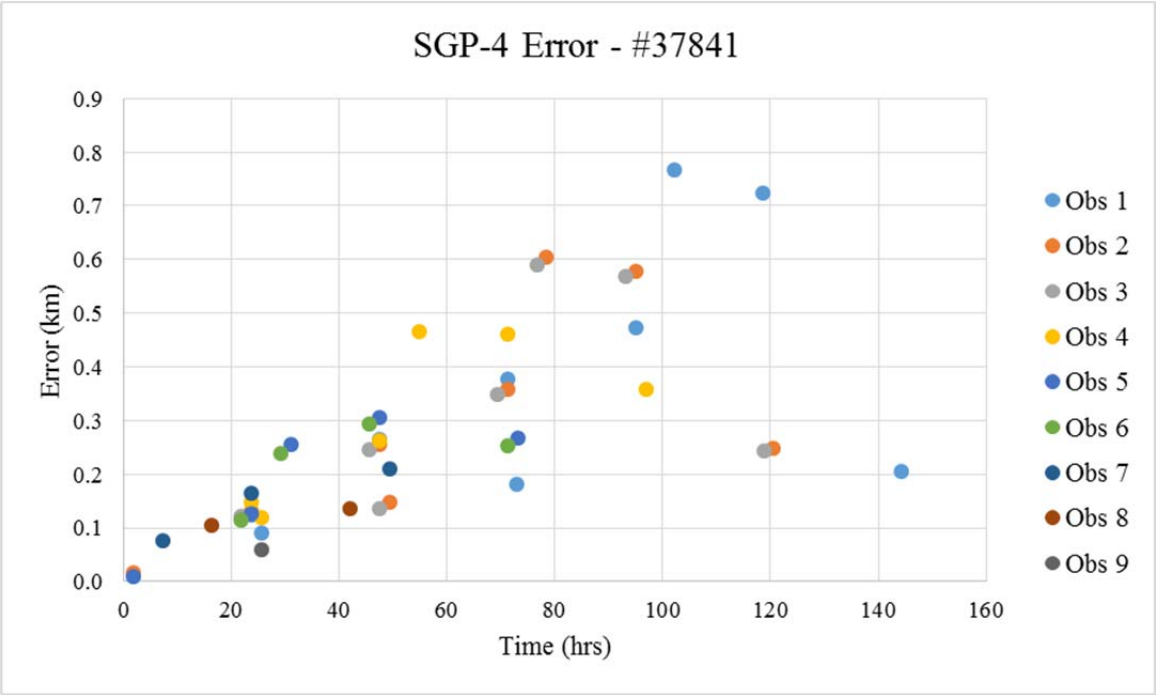

Figure 162. Error of the SGP-4 Propagator Over Time–#37841

DDDD. CATALOG NUMBER 37842–PSLV ROCKET BODY

This ephemeris data represents one of three samples for inclinations 10–20 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 244. Two-Line Element for #37842 30NOV–7DEC15

Obs	TLE
1	1 37842U 11058E 15334.79977945 +.00000326 +00000-0 +23194-4 0 9996 2 37842 019.7925 130.5977 0060138 019.0478 341.2160 14.21016143214971
2	1 37842U 11058E 15335.50198017 .00000323 00000-0 21724-4 0 9995 2 37842 19.7925 126.2752 0060164 26.9201 333.4306 14.21016165215187
3	1 37842U 11058E 15335.78286003 +.00000315 +00000-0 +18272-4 0 9993 2 37842 019.7925 124.5460 0060156 030.0596 330.3243 14.21016181215115
4	1 37842U 11058E 15336.76593809 .00000310 00000-0 16033-4 0 9995 2 37842 19.7927 118.4941 0060174 41.0682 319.4232 14.21016226215364
5	1 37842U 11058E 15337.74901302 +.00000316 +00000-0 +18831-4 0 9999 2 37842 019.7929 112.4427 0060209 052.0527 308.5298 14.21016337215395
6	1 37842U 11058E 15338.73208392 .00000317 00000-0 19165-4 0 9990 2 37842 19.7931 106.3911 0060216 63.0451 297.6087 14.21016439215649
7	1 37842U 11058E 15339.71515031 +.00000327 +00000-0 +23348-4 0 9999 2 37842 019.7933 100.3396 0060207 074.0523 286.6504 14.21016593215670
8	1 37842U 11058E 15340.48755633 .00000330 00000-0 24812-4 0 9990 2 37842 19.7934 95.5849 0060206 82.7077 278.0165 14.21016678215894
9	1 37842U 11058E 15340.69821200 +.00000331 +00000-0 +25008-4 0 9996 2 37842 019.7934 094.2883 0060209 085.0533 275.6741 14.21016719215815
10	1 37842U 11058E 15341.54083238 .00000331 00000-0 24987-4 0 9997 2 37842 19.7936 89.1017 0060207 94.4778 266.2505 14.21016809216042

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 245. Ephemeris Data Derived From TLEs for #37842

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	19 : 11 : 40.944	14.2102	0.0060138	19.7925	19.0478	130.5977	341.2160
2	1-Dec	12 : 2 : 51.087	14.2102	60164	19.7925	26.9201	126.2752	333.4306
3	1-Dec	18 : 47 : 19.107	14.2102	60156	19.7925	30.0596	124.5460	330.3243
4	2-Dec	18 : 22 : 57.051	14.2102	60174	19.7927	41.0682	118.4941	319.4232
5	3-Dec	17 : 58 : 34.725	14.2102	60209	19.7929	52.0527	112.4427	308.5298
6	4-Dec	17 : 34 : 12.051	14.2102	60216	19.7931	63.0451	106.3911	297.6087
7	5-Dec	17 : 9 : 48.987	14.2102	60207	19.7933	74.0523	100.3396	286.6504
8	6-Dec	11 : 42 : 4.867	14.2102	60206	19.7934	82.7077	95.5849	278.0165
9	6-Dec	16 : 45 : 25.517	14.2102	60209	19.7934	85.0533	94.2883	275.6741
10	7-Dec	12 : 58 : 47.918	14.2102	60207	19.7936	94.4778	89.1017	266.2505

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 246. Error of Propagated Ephemeris for #37842

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.169	472	16.85282
→3	0.222	675	23.59393
→4	0.458	1380	47.18781
→5	0.690	2077	70.78161
→6	0.919	2763	94.37531
→7	1.126	3423	117.96890
→8	1.307	3942	136.50665
→9	1.347	4074	141.56238
→10	1.532	4603	161.78527
Obs 2→3	0.086	203	6.74112
→4	0.297	912	30.33499
→5	0.511	1617	53.92879
→6	0.734	2312	77.52249
→7	0.941	2987	101.11608
→8	1.116	3515	119.65383
→9	1.155	3652	124.70956
→10	1.327	4196	144.93245
Obs 3→4	0.229	710	23.59387
→5	0.448	1417	47.18767
→6	0.666	2116	70.78137
→7	0.871	2796	94.37497
→8	1.044	3328	112.91271
→9	1.082	3466	117.96845
→10	1.249	4016	138.19134

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→5	0.214	711	23.59380
→6	0.431	1419	47.18750
→7	0.647	2115	70.78109
→8	0.823	2659	89.31884
→9	0.863	2802	94.37457
→10	1.031	3372	114.59746
Obs 5→6	0.220	712	23.59370
→7	0.444	1419	47.18729
→8	0.616	1972	65.72504
→9	0.657	2120	70.78078
→10	0.823	2706	91.00366
Obs 6→7	0.230	713	23.59359
→8	0.399	1271	42.13134
→9	0.441	1422	47.18707
→10	0.606	2021	67.40996
Obs 7→8	0.169	561	18.53774
→9	0.210	714	23.59348
→10	0.381	1322	43.81637
Obs 8→9	0.043	153	5.05574
→10	0.214	765	25.27863
Obs 9→10	0.174	613	20.22289

Figure 163. Error of the Two-Body Propagator Over Time–#37842

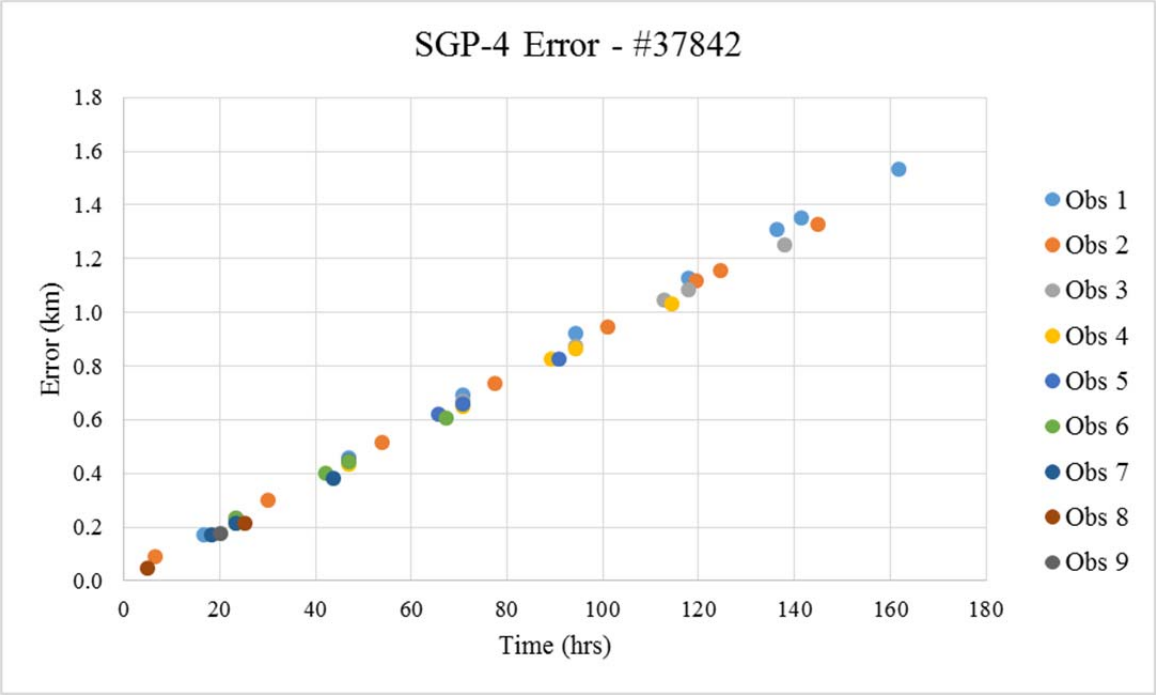

Figure 164. Error of the SGP-4 Propagator Over Time–#37842

EEEE. CATALOG NUMBER 38358–NUSTAR

This ephemeris data represents one of three samples for inclinations 0–10 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 247. Two-Line Element for #38358 30NOV–7DEC15

Obs	TLE
1	1 38358U 12031A 15335.10830072 .00001964 00000-0 13747-3 0 9997 2 38358 6.0267 81.3556 0011420 93.9823 266.1612 14.86999025188318
2	1 38358U 12031A 15336.18141093 .00001849 00000-0 12493-3 0 9993 2 38358 6.0268 73.5718 0011506 110.3514 249.7851 14.87001017188473
3	1 38358U 12031A 15337.12038000 +.00001816 +00000-0 +12140-3 0 9994 2 38358 006.0269 066.7644 0011549 124.5263 235.5956 14.87003096188615
4	1 38358U 12031A 15337.99227795 .00001681 00000-0 10665-3 0 9990 2 38358 6.0270 60.4433 0011622 137.6119 222.4908 14.87004324188742
5	1 38358U 12031A 15339.13244897 .00001870 00000-0 12722-3 0 9996 2 38358 6.0272 52.1775 0011741 154.5340 205.5368 14.87007878188915
6	1 38358U 12031A 15340.00434221 +.00001897 +00000-0 +13009-3 0 9994 2 38358 006.0271 045.8578 0011906 167.3244 192.7184 14.87010153189040
7	1 38358U 12031A 15341.07744032 .00002086 00000-0 15061-3 0 9997 2 38358 6.0274 38.0829 0012052 182.4281 177.5790 14.87013698189207

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 248. Ephemeris Data Derived From TLEs for #38358

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	2 : 35 : 57.182	14.8700	0.0011420	6.0267	93.9823	81.3556	266.1612
2	2-Dec	4 : 21 : 13.904	14.8700	11506	6.0268	110.3514	73.5718	249.7851
3	3-Dec	2 : 53 : 20.832	14.8700	11549	6.0269	124.5263	66.7644	235.5956
4	3-Dec	23 : 48 : 52.815	14.8700	11622	6.0270	137.6119	60.4433	222.4908
5	5-Dec	3 : 10 : 43.591	14.8701	11741	6.0272	154.5340	52.1775	205.5368
6	6-Dec	0 : 6 : 15.167	14.8701	11906	6.0271	167.3244	45.8578	192.7184
7	7-Dec	1 : 51 : 30.844	14.8701	12052	6.0274	182.4281	38.0829	177.5790

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 249. Error of Propagated Ephemeris for #38358

	Error (km)		Elapsed
	SGP-4	Two Body	Time (hr)
Obs 1→2	0.401	941	25.75465
→3	0.692	1762	48.28990
→4	1.122	2518	69.21545
→5	1.673	3495	96.57956
→6	1.962	4231	117.50500
→7	2.383	5116	143.25935
Obs 2→3	0.266	825	22.53526
→4	0.463	1588	43.46081
→5	0.742	2580	70.82491
→6	1.032	3329	91.75035
→7	1.374	4236	117.50471
Obs 3→4	0.245	767	20.92555
→5	0.506	1766	48.28966
→6	0.826	2525	69.21509
→7	1.276	3447	94.96945
Obs 4→5	0.571	1003	27.36410
→6	1.394	1768	48.28954
→7	2.516	2701	74.04390
Obs 5→6	0.298	765	20.92544
→7	0.582	1704	46.67979
Obs 6→7	0.215	942	25.75435

Figure 165. Error of the Two-Body Propagator Over Time–#38358

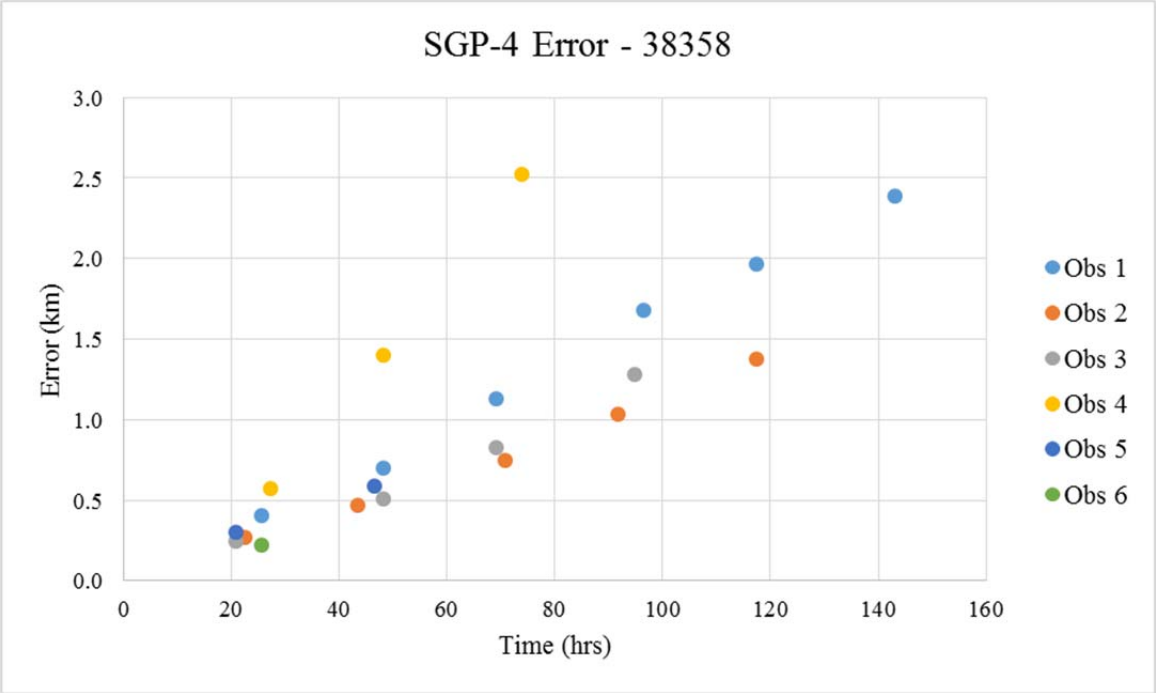

Figure 166. Error of the SGP-4 Propagator Over Time–#38358

FFFF. CATALOG NUMBER 39451–SWARM B

This ephemeris data represents one of three samples for semi-major axes 6800–6900 km in the experiment to determine the effect of the altitude on propagator accuracy.

Table 250. Two-Line Element for #39451 30NOV–7DEC15

Obs	TLE
1	1 39451U 13067A 15334.93394901 +.00001548 +00000-0 +70148-4 0 9995
	2 39451 087.7545 056.5569 0003447 075.6810 284.4817 15.20096603097542
2	1 39451U 13067A 15335.85557914 .00001556 00000-0 70523-4 0 9998
	2 39451 87.7545 56.2819 0003409 74.7691 285.3930 15.20099577112246
3	1 39451U 13067A 15335.92140978 +.00001575 +00000-0 +71398-4 0 9996
	2 39451 087.7545 056.2622 0003406 074.7042 285.4579 15.20099872097694
4	1 39451U 13067A 15336.90886906 +.00001363 +00000-0 +61578-4 0 9997
	2 39451 087.7544 055.9676 0003361 073.8284 286.3331 15.20101750097848
5	1 39451U 13067A 15337.17219113 .00001377 00000-0 62225-4 0 9992
	2 39451 87.7544 55.8890 0003345 73.5330 286.6282 15.20102553112440
6	1 39451U 13067A 15337.89632659 +.00001227 +00000-0 +55246-4 0 9994
	2 39451 087.7544 055.6729 0003304 072.7771 287.3835 15.20103721097996
7	1 39451U 13067A 15338.81795204 .00001263 00000-0 56890-4 0 9999
	2 39451 87.7543 55.3978 0003252 72.0841 288.0757 15.20106448112696
8	1 39451U 13067A 15338.94961293 +.00001159 +00000-0 +52102-4 0 9992
	2 39451 087.7543 055.3585 0003246 072.1031 288.0567 15.20106167098156
9	1 39451U 13067A 15339.93706684 +.00001354 +00000-0 +61130-4 0 9991
	2 39451 087.7543 055.0637 0003185 071.4012 288.7578 15.20109916098305
10	1 39451U 13067A 15340.20038761 .00001328 00000-0 59901-4 0 9991
	2 39451 87.7543 54.9851 0003167 71.2750 288.8838 15.20110577112906
11	1 39451U 13067A 15340.92451883 +.00001510 +00000-0 +68349-4 0 9993
	2 39451 087.7542 054.7690 0003134 070.9854 289.1730 15.20113556098457
12	1 39451U 13067A 15341.51698932 .00001514 00000-0 68515-4 0 9996
	2 39451 87.7542 54.5921 0003094 70.5797 289.5782 15.20115178113102

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 251. Ephemeris Data Derived From TLEs for #39451

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	30-Nov	22 : 24 : 53.194	15.2010	0.0003447	87.7545	75.6810	56.5569	284.4817
2	1-Dec	20 : 32 : 2.038	15.2010	3409	87.7545	74.7691	56.2819	285.3930
3	1-Dec	22 : 6 : 49.805	15.2010	3406	87.7545	74.7042	56.2622	285.4579
4	2-Dec	21 : 48 : 46.287	15.2010	3361	87.7544	73.8284	55.9676	286.3331
5	3-Dec	4 : 7 : 57.314	15.2010	3345	87.7544	73.5330	55.8890	286.6282
6	3-Dec	21 : 30 : 42.617	15.2010	3304	87.7544	72.7771	55.6729	287.3835
7	4-Dec	19 : 37 : 51.056	15.2011	3252	87.7543	72.0841	55.3978	288.0757
8	4-Dec	22 : 47 : 26.557	15.2011	3246	87.7543	72.1031	55.3585	288.0567
9	5-Dec	22 : 29 : 22.575	15.2011	3185	87.7543	71.4012	55.0637	288.7578
10	6-Dec	4 : 48 : 33.490	15.2011	3167	87.7543	71.2750	54.9851	288.8838
11	6-Dec	22 : 11 : 18.427	15.2011	3134	87.7542	70.9854	54.7690	289.1730
12	7-Dec	12 : 24 : 27.877	15.2012	3094	87.7542	70.5797	54.5921	289.5782

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 252. Error of Propagated Ephemeris for #39451

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.143	422	22.11912
→3	0.174	452	23.69906
→4	0.246	902	47.39808
→5	0.276	1022	53.71781
→6	0.538	1350	71.09706
→7	0.973	1766	93.21607
→8	1.203	1826	96.37593
→9	1.844	2268	120.07483
→10	2.037	2385	126.39453
→11	2.521	2706	143.77368
→12	3.061	2968	157.99297
Obs 2→3	0.023	30	1.57994
→4	0.265	480	25.27896
→5	0.304	601	31.59869
→6	0.697	930	48.97794
→7	1.232	1347	71.09695
→8	1.481	1407	74.25681
→9	2.218	1851	97.95570
→10	2.439	1969	104.27540
→11	2.993	2292	121.65455
→12	3.600	2555	135.87384
Obs 3→4	0.323	451	23.69902
→5	0.374	571	30.01875
→6	0.818	900	47.39800
→7	1.426	1317	69.51701
→8	1.688	1377	72.67688
→9	2.521	1821	96.37577
→10	2.770	1939	102.69547
→11	3.407	2262	120.07462
→12	4.089	2525	134.29391
Obs 4→5	0.102	120	6.31973
→6	0.167	450	23.69898
→7	0.335	868	45.81799
→8	0.274	928	48.97785
Obs 4→9	0.450	1373	72.67675
→10	0.502	1492	78.99645
→11	0.723	1816	96.37559
→12	0.841	2081	110.59489
Obs 5→6	0.087	330	17.37925
→7	0.211	748	39.49826
→8	0.240	808	42.65812
→9	0.345	1254	66.35702
→10	0.381	1372	72.67672
→11	0.508	1697	90.05586
→12	0.591	1962	104.27516
Obs 6→7	0.460	419	22.11901
→8	0.390	478	25.27887
→9	1.022	925	48.97777
→10	1.208	1044	55.29746
→11	1.893	1370	72.67661
→12	2.397	1635	86.89591
Obs 7→8	0.105	60	3.15986
→9	0.326	507	26.85876
→10	0.444	626	33.17845
→11	0.940	953	50.55760
→12	1.275	1219	64.77689
Obs 8→9	0.710	447	23.69889
→10	0.922	566	30.01859
→11	1.716	893	47.39774
→12	2.325	1159	61.61703
Obs 9→10	0.047	119	6.31970
→11	0.310	446	23.69885
→12	0.426	713	37.91814
Obs 10→11	0.288	327	17.37915
→12	0.424	594	31.59844
Obs 11→12	0.202	267	14.21929

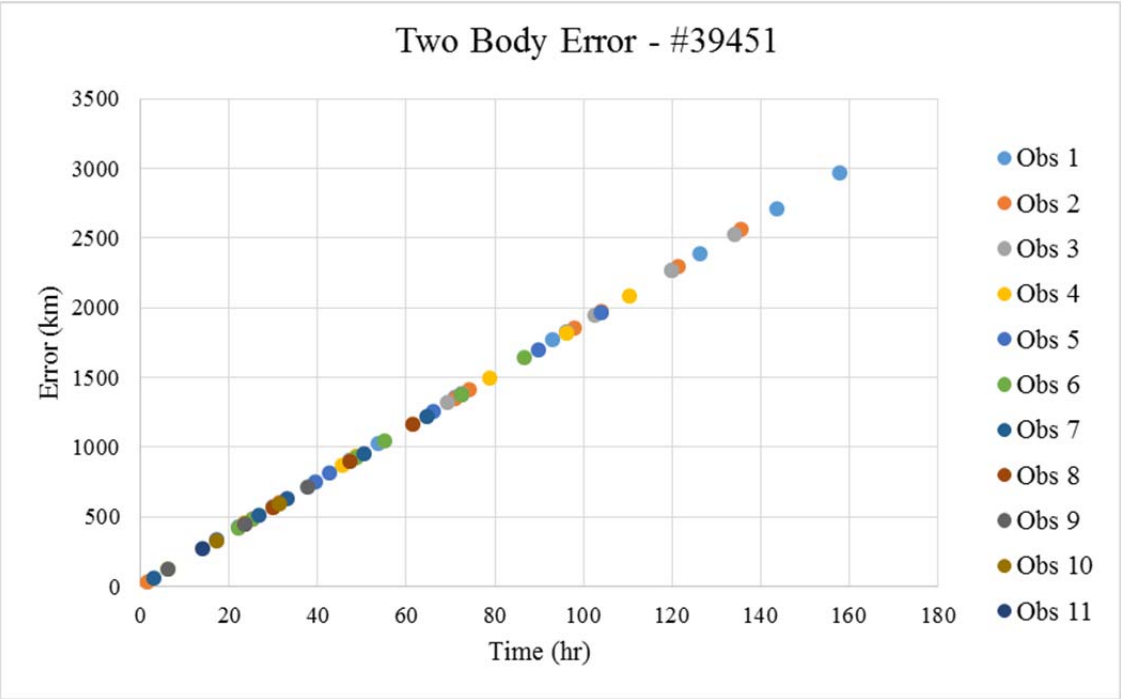

Figure 167. Error of the Two-Body Propagator Over Time–#39451

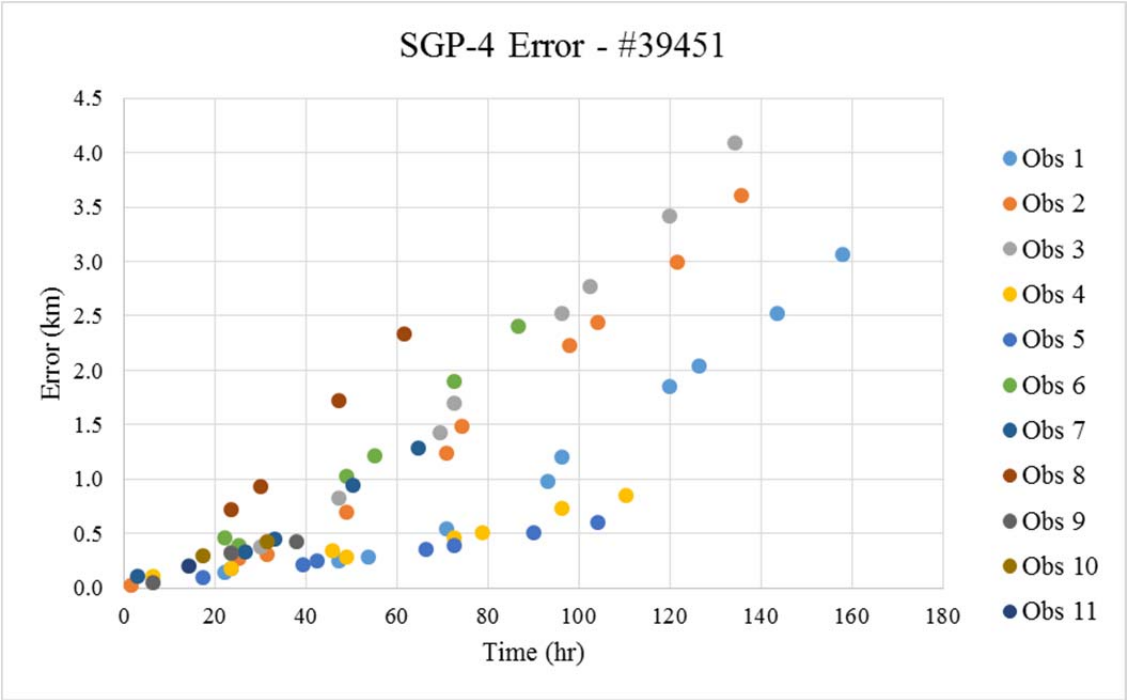

Figure 168. Error of the SGP-4 Propagator Over Time–#39451

GGGG. CATALOG NUMBER 39766–ALOS 2

This ephemeris data represents one of three samples for inclinations 90–100 degrees used in the experiment to determine the effect of inclination on propagator accuracy.

Table 253. Two-Line Element for #39766 30NOV–7DEC15

Obs	TLE
1	1 39766U 14029A 15335.19234102 -.00000124 00000-0 -97490-5 0 9999 2 39766 97.9219 69.6357 0001434 83.9623 276.1777 14.79468385 82214
2	1 39766U 14029A 15335.53050493 -.00000054 00000-0 -34573-6 0 9992 2 39766 97.9220 69.9690 0001397 86.1971 273.9432 14.79469037 82261
3	1 39766U 14029A 15335.80103592 .00000042 00000-0 12521-4 0 9993 2 39766 97.9220 70.2357 0001538 87.7886 272.3542 14.79469941 82309
4	1 39766U 14029A 15336.20683181 .00000126 00000-0 23713-4 0 9993 2 39766 97.9220 70.6354 0001513 86.1231 274.0177 14.79470895 82369
5	1 39766U 14029A 15336.47736256 .00000163 00000-0 28734-4 0 9993 2 39766 97.9220 70.9020 0001502 86.5429 273.5972 14.79471374 82408
6	1 39766U 14029A 15336.81552629 .00000195 00000-0 32938-4 0 9997 2 39766 97.9219 71.2353 0001515 84.9791 275.1612 14.79471876 82458
7	1 39766U 14029A 15337.15368920 .00000275 00000-0 43735-4 0 9990 2 39766 97.9220 71.5685 0001485 82.6442 277.4967 14.79472938 82509
8	1 39766U 14029A 15337.35658699 .00000289 00000-0 45538-4 0 9995 2 39766 97.9221 71.7685 0001481 83.1133 277.0266 14.79473234 82532
9	1 39766U 14029A 15337.83001523 .00000375 00000-0 57100-4 0 9990 2 39766 97.9220 72.2354 0001523 85.1164 275.0267 14.79474519 82607
10	1 39766U 14029A 15338.16817725 .00000472 00000-0 70112-4 0 9992 2 39766 97.9219 72.5685 0001485 86.0394 274.1038 14.79475803 82655
11	1 39766U 14029A 15338.50633917 .00000522 00000-0 76799-4 0 9992 2 39766 97.9218 72.9018 0001431 85.9170 274.2221 14.79476620 82708
12	1 39766U 14029A 15338.84450182 .00000542 00000-0 79421-4 0 9997 2 39766 97.9217 73.2350 0001457 83.9032 276.2331 14.79477092 82756
13	1 39766U 14029A 15339.18266514 .00000500 00000-0 73818-4 0 9997 2 39766 97.9217 73.5684 0001445 79.3500 280.7792 14.79476795 82801

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 254. Ephemeris Data Derived From TLEs for #39766

Obs	Day	Time	MM (Rev/day)	ECC	INC (°)	Arg of Perigee (°)	RAAN (°)	Mean Anom (°)
1	1-Dec	4 : 36 : 58.264	14.7947	0.0001434	97.9219	83.9623	69.6357	276.1777
2	1-Dec	12 : 43 : 55.626	14.7947	1397	97.9220	86.1971	69.9690	273.9432
3	1-Dec	19 : 13 : 29.503	14.7947	1538	97.9220	87.7886	70.2357	272.3542
4	2-Dec	4 : 57 : 50.268	14.7947	1513	97.9220	86.1231	70.6354	274.0177
5	2-Dec	11 : 27 : 24.125	14.7947	1502	97.9220	86.5429	70.9020	273.5972
6	2-Dec	19 : 34 : 21.471	14.7947	1515	97.9219	84.9791	71.2353	275.1612
7	3-Dec	3 : 41 : 18.747	14.7947	1485	97.9220	82.6442	71.5685	277.4967
8	3-Dec	8 : 33 : 29.116	14.7947	1481	97.9221	83.1133	71.7685	277.0266
9	3-Dec	19 : 55 : 13.316	14.7947	1523	97.9220	85.1164	72.2354	275.0267
10	4-Dec	4 : 2 : 10.514	14.7948	1485	97.9219	86.0394	72.5685	274.1038
11	4-Dec	12 : 9 : 7.704	14.7948	1431	97.9218	85.9170	72.9018	274.2221
12	4-Dec	20 : 16 : 4.957	14.7948	1457	97.9217	83.9032	73.2350	276.2331
13	5-Dec	4 : 23 : 2.268	14.7948	1445	97.9217	79.3500	73.5684	280.7792

Adapted from [1]: JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle

Table 255. Error of Propagated Ephemeris for #39766

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 1→2	0.765	145	8.11593
→3	1.503	260	14.60868
→4	2.649	434	24.34778
→5	3.376	550	30.84052
→6	4.201	695	38.95645
→7	5.683	839	47.07236
→8	6.355	925	51.94190
→9	8.484	1126	63.30418
→10	10.507	1269	71.42007
→11	12.110	1413	79.53596
→12	13.297	1556	87.65186
→13	13.595	1700	95.76778
Obs 2→3	0.658	116	6.49274
→4	1.667	289	16.23185
→5	2.302	405	22.72458
→6	3.002	550	30.84051
→7	4.352	694	38.95642
→8	4.940	781	43.82597
→9	6.867	982	55.18825
→10	8.737	1125	63.30414
→11	10.178	1269	71.42002
→12	11.198	1412	79.53593
→13	11.321	1557	87.65185
Obs 3→4	0.842	174	9.73910
→5	1.360	289	16.23184
→6	1.903	434	24.34777
→7	3.085	578	32.46368
→8	3.568	665	37.33323
→9	5.237	866	48.69550
→10	6.910	1010	56.81139
→11	8.145	1153	64.92728
→12	8.949	1297	73.04318
→13	8.846	1442	81.15910
Obs 4→5	0.410	116	6.49274
→6	0.811	261	14.60867
→7	1.843	405	22.72458
→8	2.232	491	27.59412
→9	3.669	693	38.95640
→10	5.167	837	47.07229

	Error (km) SGP-4	Error (km) Two Body	Elapsed Time (hr)
Obs 4→11	6.219	980	55.18818
→12	6.830	1124	63.30408
→13	6.527	1269	71.42000
Obs 5→6	0.344	145	8.11593
→7	1.315	289	16.23184
→8	1.663	376	21.10139
→9	3.006	577	32.46366
→10	4.431	721	40.57955
→11	5.405	865	48.69544
→12	5.936	1009	56.81134
→13	5.549	1154	64.92726
Obs 6→7	0.916	144	8.11591
→8	1.231	231	12.98546
→9	2.489	433	24.34773
→10	3.849	576	32.46362
→11	4.757	720	40.57951
→12	5.217	865	48.69541
→13	4.755	1009	56.81133
Obs 7→8	0.234	87	4.86955
→9	1.290	289	16.23182
→10	2.495	432	24.34771
→11	3.239	576	32.46360
→12	3.528	721	40.57950
→13	2.887	865	48.69542
Obs 8→9	1.022	202	11.36228
→10	2.201	346	19.47817
→11	2.918	490	27.59405
→12	3.177	634	35.70996
→13	2.506	779	43.82588
Obs 9→10	1.036	144	8.11589
→11	1.599	288	16.23177
→12	1.697	432	24.34768
→13	0.856	578	32.46360
Obs 10→11	0.413	146	8.11589
→12	0.350	291	16.23179
→13	0.664	438	24.34771
Obs 11→12	0.134	146	8.11590
→13	1.222	293	16.23182
Obs 12→13	1.102	147	8.11592

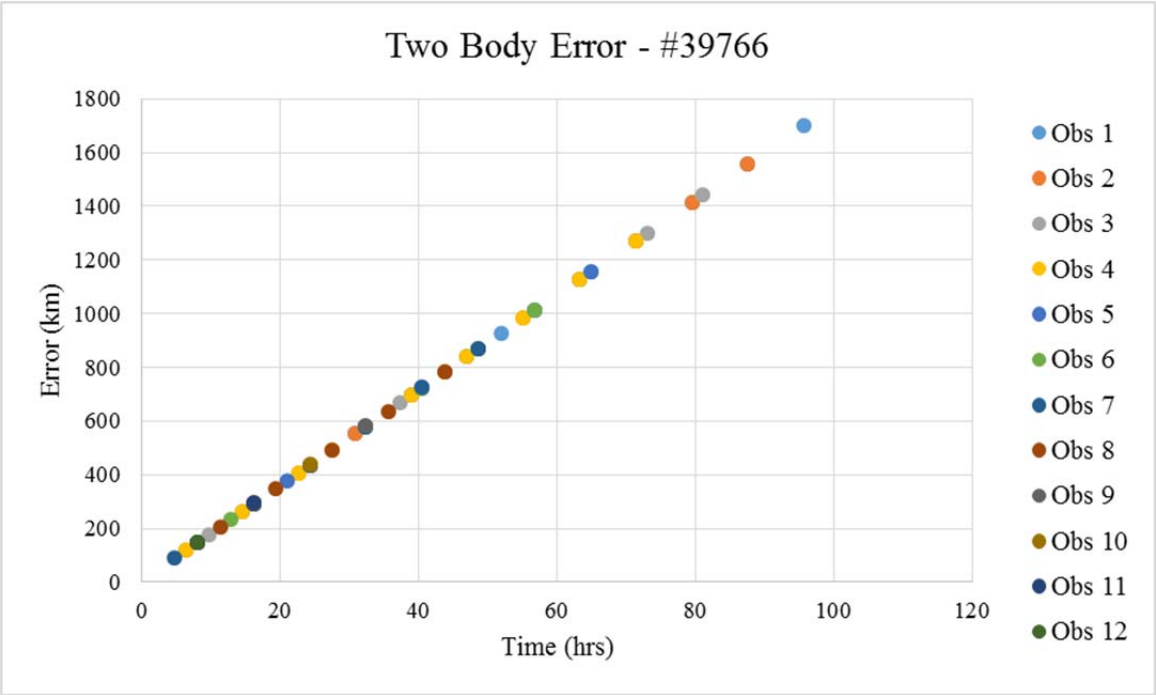

Figure 169. Error of the Two-Body Propagator Over Time–#39766

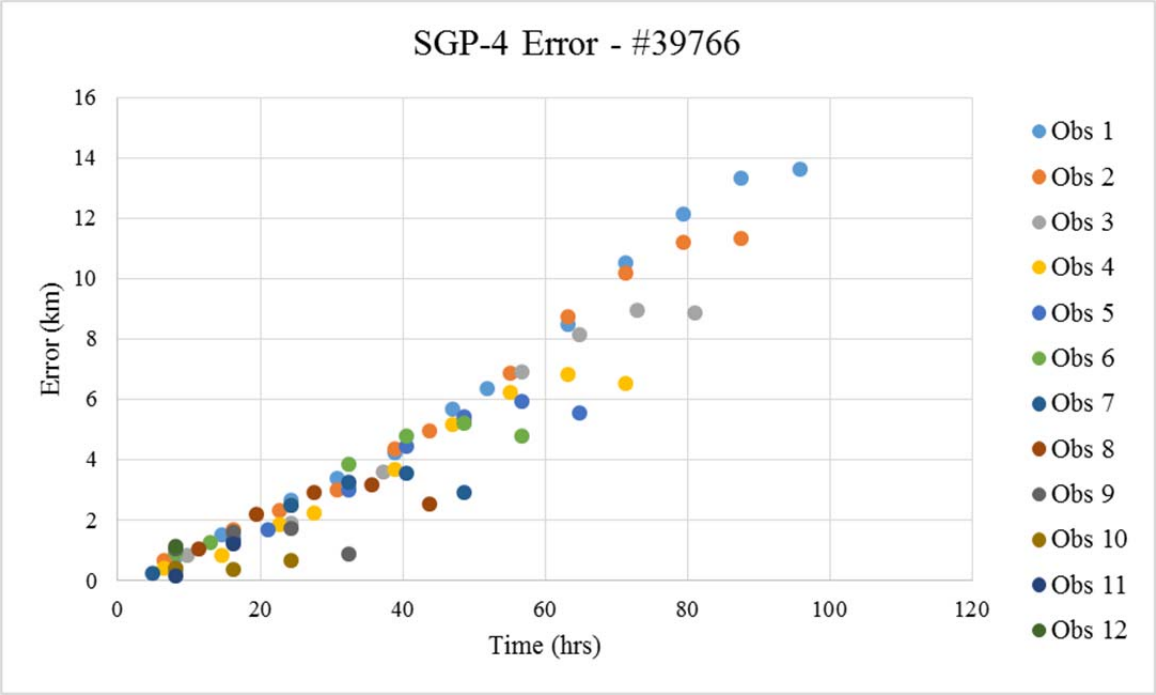

Figure 170. Error of the SGP-4 Propagator Over Time–#39766

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LIST OF REFERENCES

[1] JFCC SPACE, "Historical TLE Search," 2015. [Online]. Available: https://www.space-track.org/#/tle